Progress Report on the LMCO N+2 Low Boom Supersonic Inlet Design

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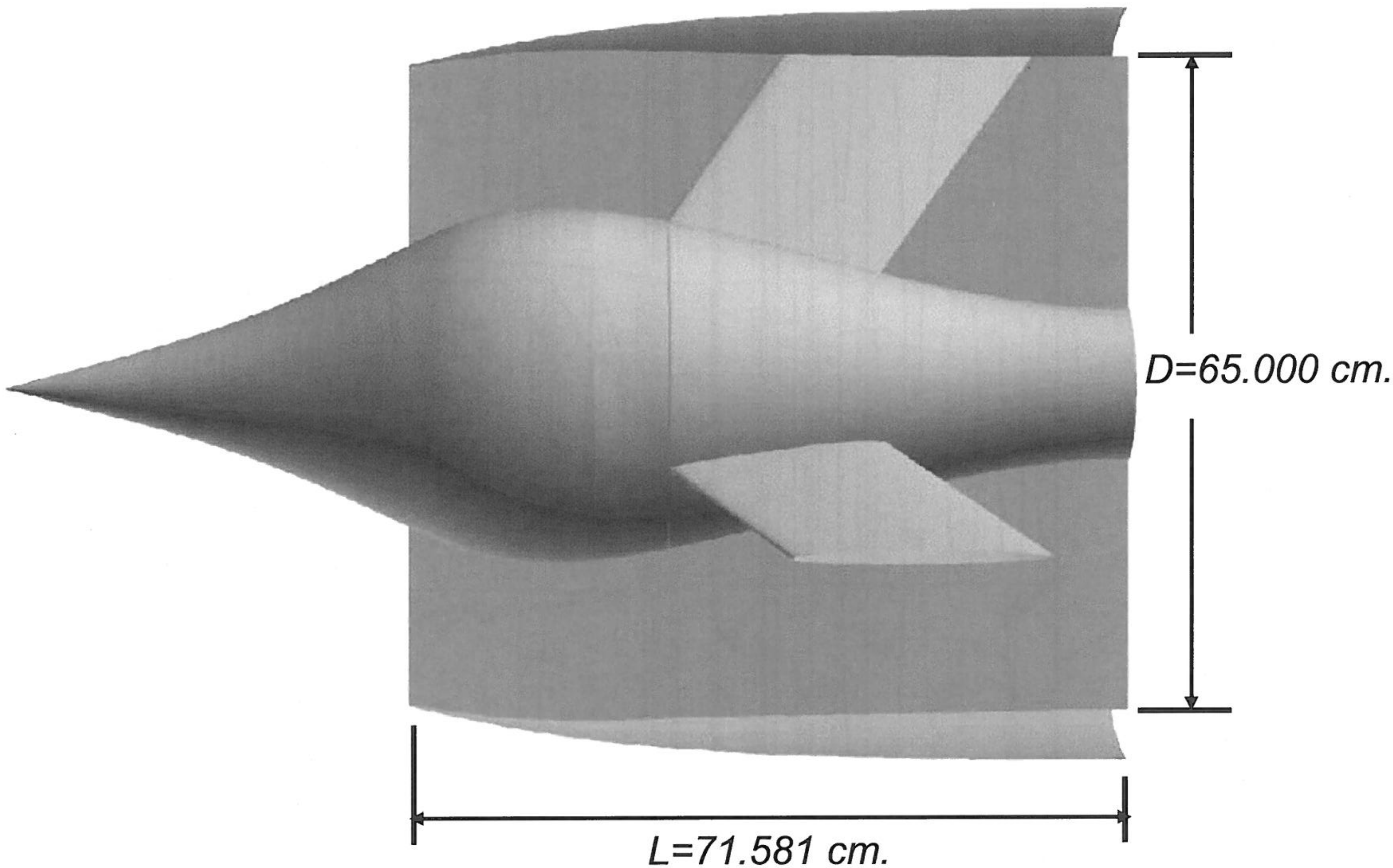
N+2 Low Boom Supersonic Inlet Design Study Research Tasks

Task 1: Screening study to establish Cain curve characteristic of the LMCO N+2 Low Boom Supersonic Inlet at a cruise Mach number of 1.7.

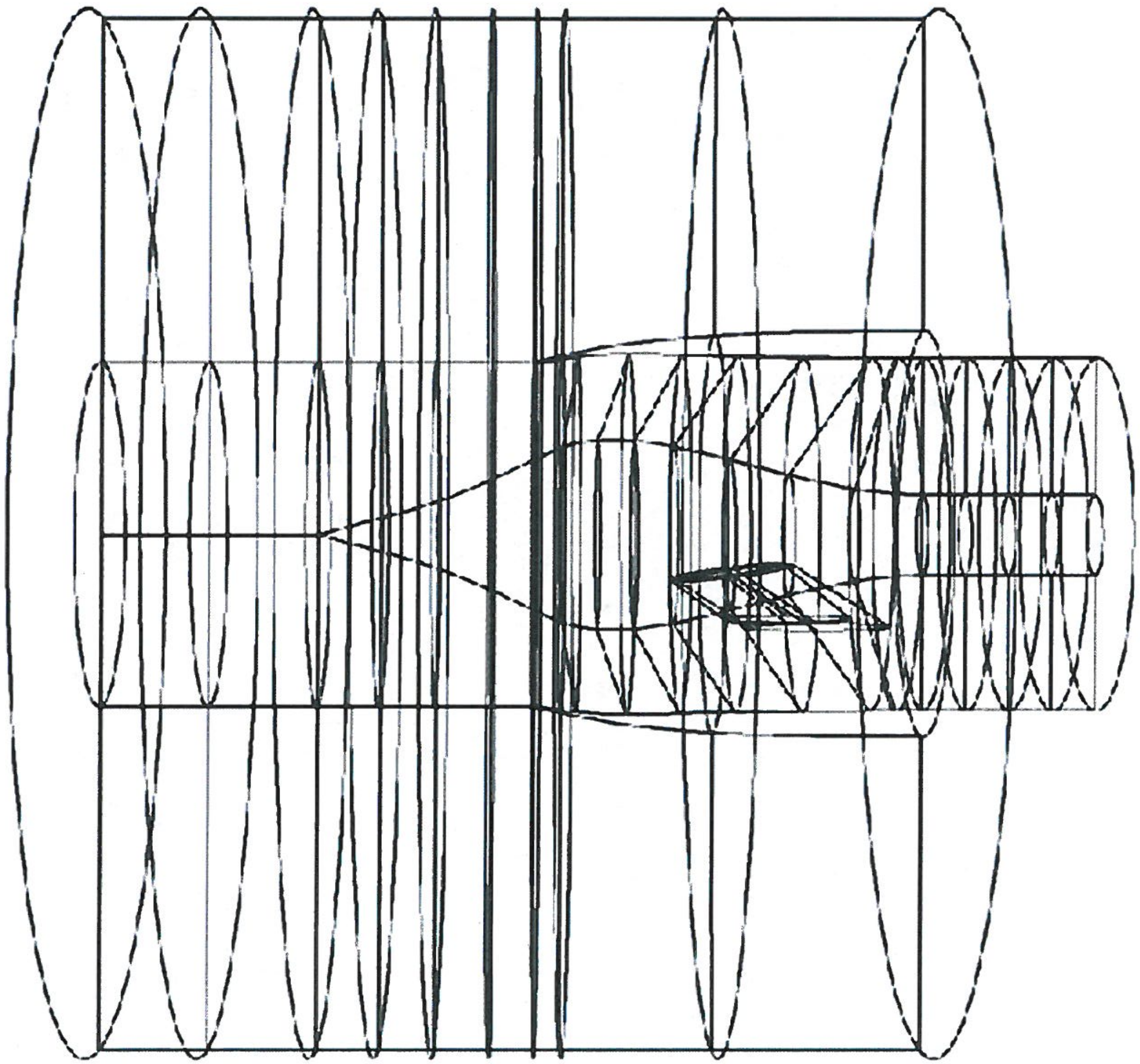
Task 2: DOE study to establish and document the compatibility characteristics of the LMCO N+2 Low Boom Supersonic inlet and compare with the HSCT requirements.

Task 3: Time series analysis to document the design implications of the unsteady interactions in the LMCO N+2 Low Boom Supersonic inlet.

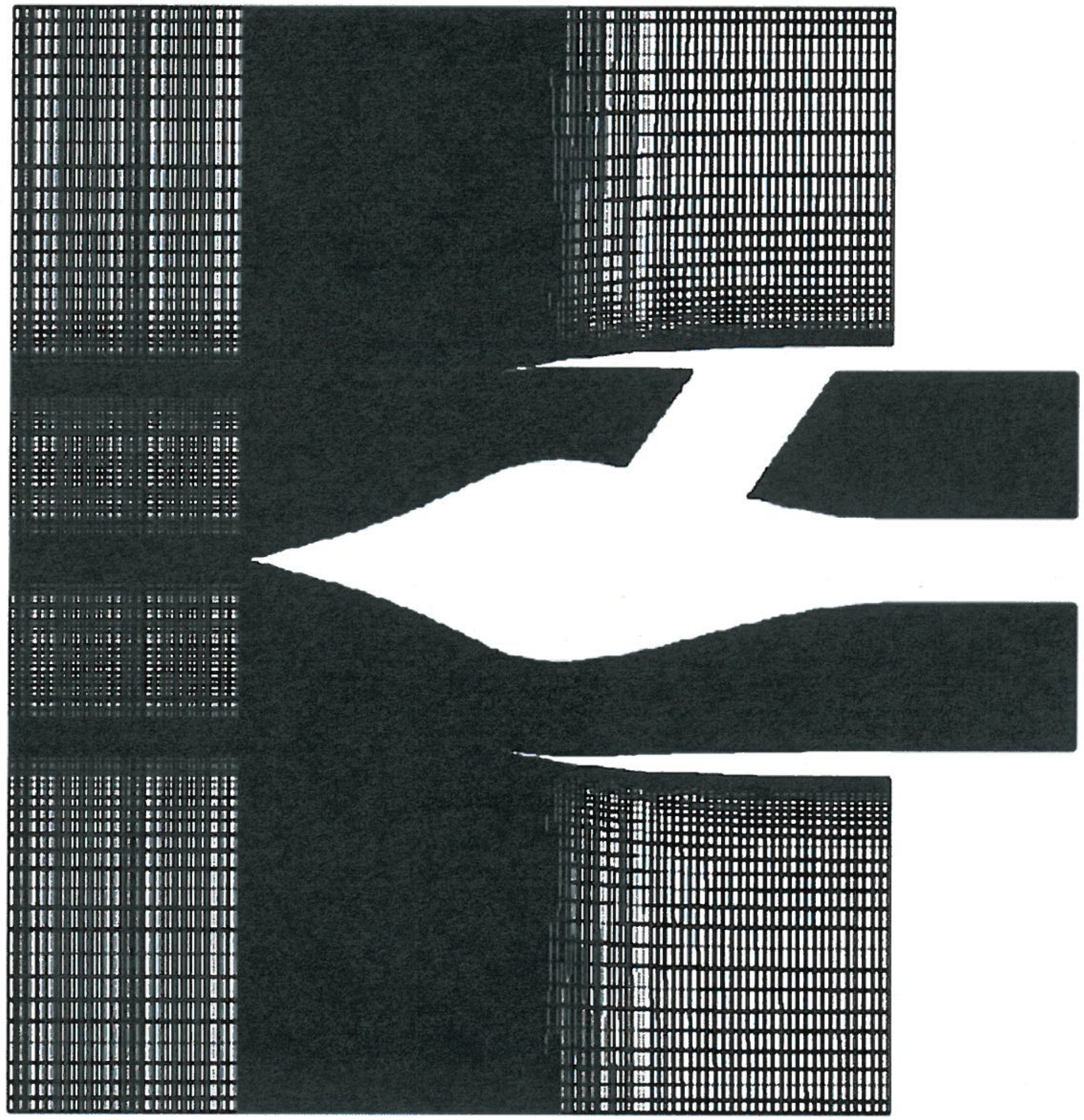
N+2 Low Boom Supersonic Inlet Design Study
Length Ratio, L/D = 1.116



N+2 Low Boom Supersonic Inlet Design Study
Blocking Topology, NBLKS = 58



N+2 Low Boom Supersonic Inlet Design Study
Computational Grid Topology



N+2 Low Boom Supersonic Inlet Design Study
Computational Grid Information

Grid	Size
Standard Mesh	3.461×10^6
Fine Mesh	27.686×10^6

N+2 Low Boom Supersonic Inlet Design Study
High Speed Civil Transport, HSR Program
Operability Goals

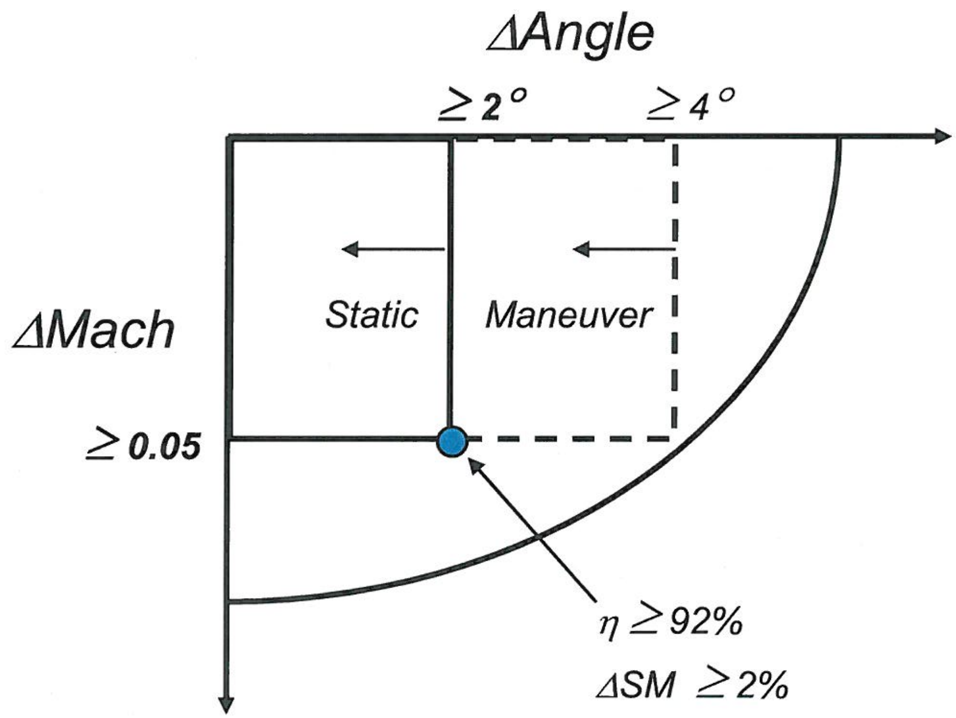
Inlet Performance ~ Cruise

- Performance
  - Recovery $\geq 92\%$
  - Bleed $\leq 5\%$
- Operability (ARP 1420)

	Nominal	Maneuver
– Hub $\leq$	0.03	0.05
– Tip $\leq$	0.03	0.05
– Cir $\leq$	0.06	0.08

- Stability Margin, $\Delta SM \geq 10\%$

Inlet Stability To Disturbances About Cruise



N+2 Low Boom Supersonic Inlet Design Study
Variables Held Constant

Variable	*Value*
Tunnel Total Pressure (lbs/ft^2), P_o	*2112.0*
Tunnlet Total Temperature (^oR), T_o	*512.0*

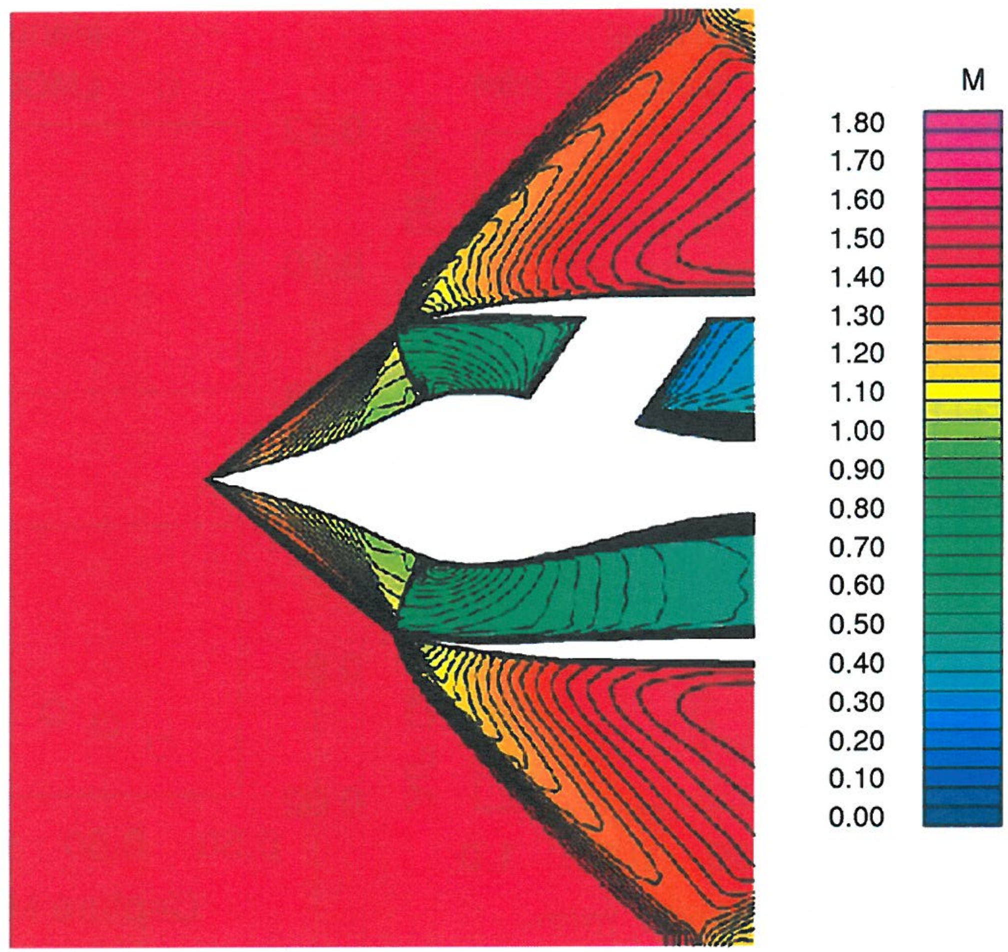
N+2 Low Boom Supersonic Inlet Design Study Factor Variables

Factor Variable	Range
Free Stream Mach Number, M_0	1.6 – 1.8
Free Stream Angle of Attack, α	0.0^o – 4.0^o
Free Stream Angle of Yaw, β	0.0^o - 4.0^o

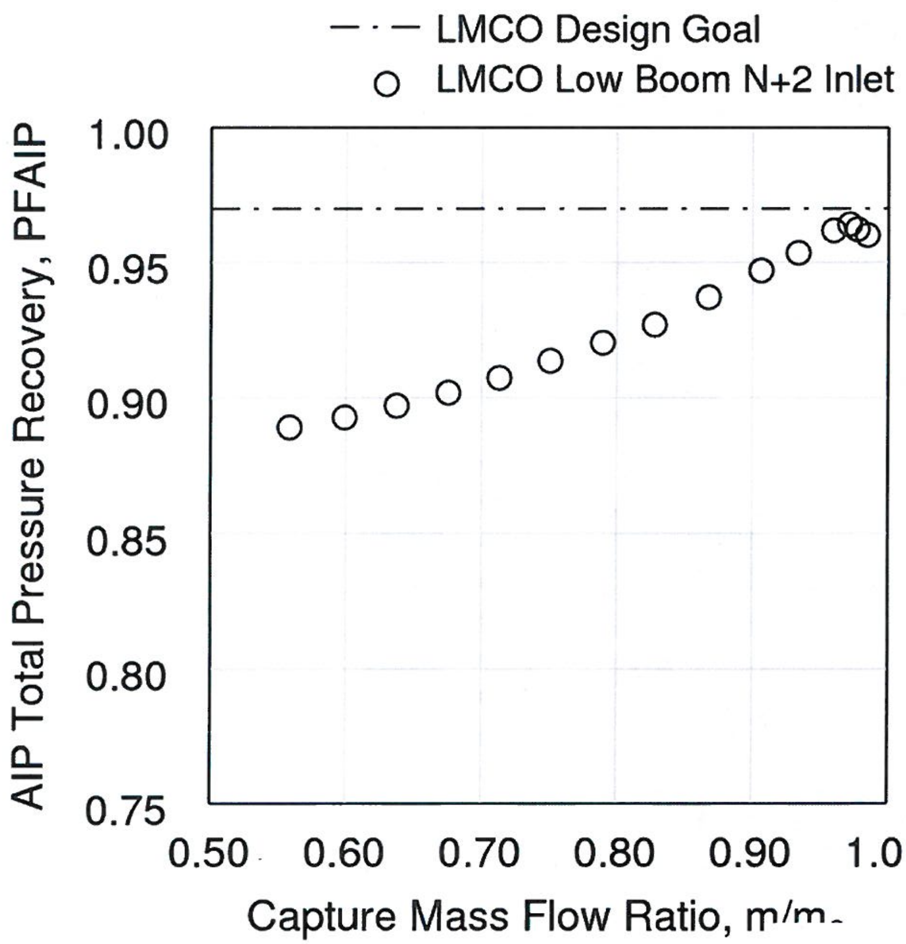
N+2 Low Boom Supersonic Inlet Design Study
ARP1420 Response Variables

Response Variable	Symbol
AIP Critical Total Pressure Recovery	PFAIP
AIP Circumferential Distortion	DPC/P
AIP Radial Hub Distortion	DPH/P
AIP Face Radial Tip Distortion	DPT/P

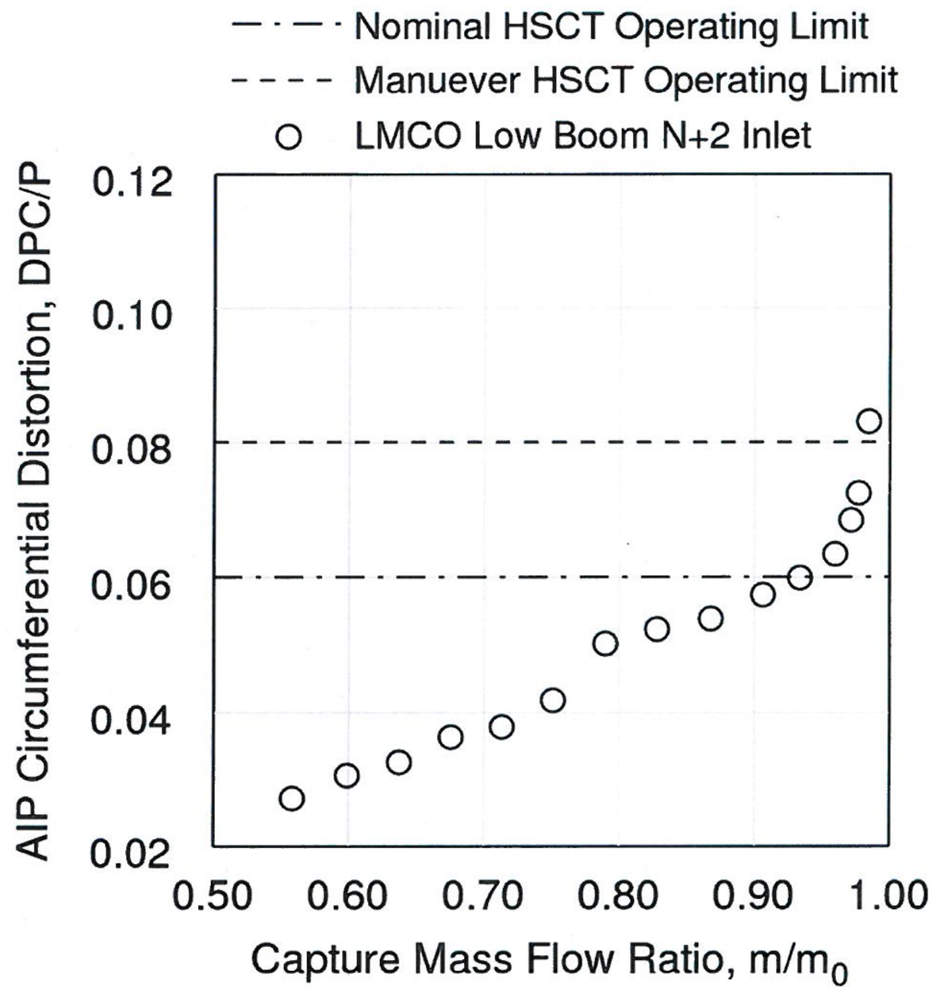
N+2 Low Boom Supersonic Inlet Design Study
Critical Inlet Operating Condition, $M_0 = 1.7$
Streamwise Mach Number Contours



N+2 Low Boom Supersonic Inlet Design Study
Cane Curve Characteristics

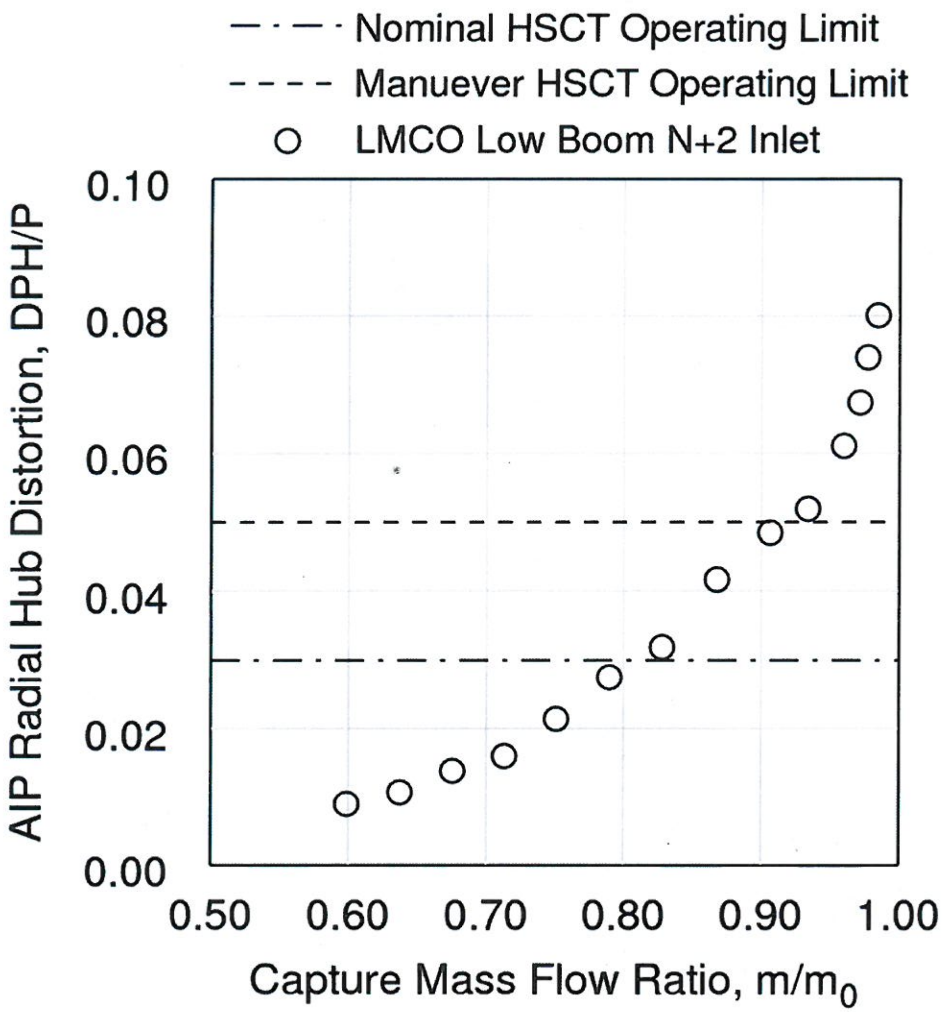


Total Pressure Recovery, PFAIP

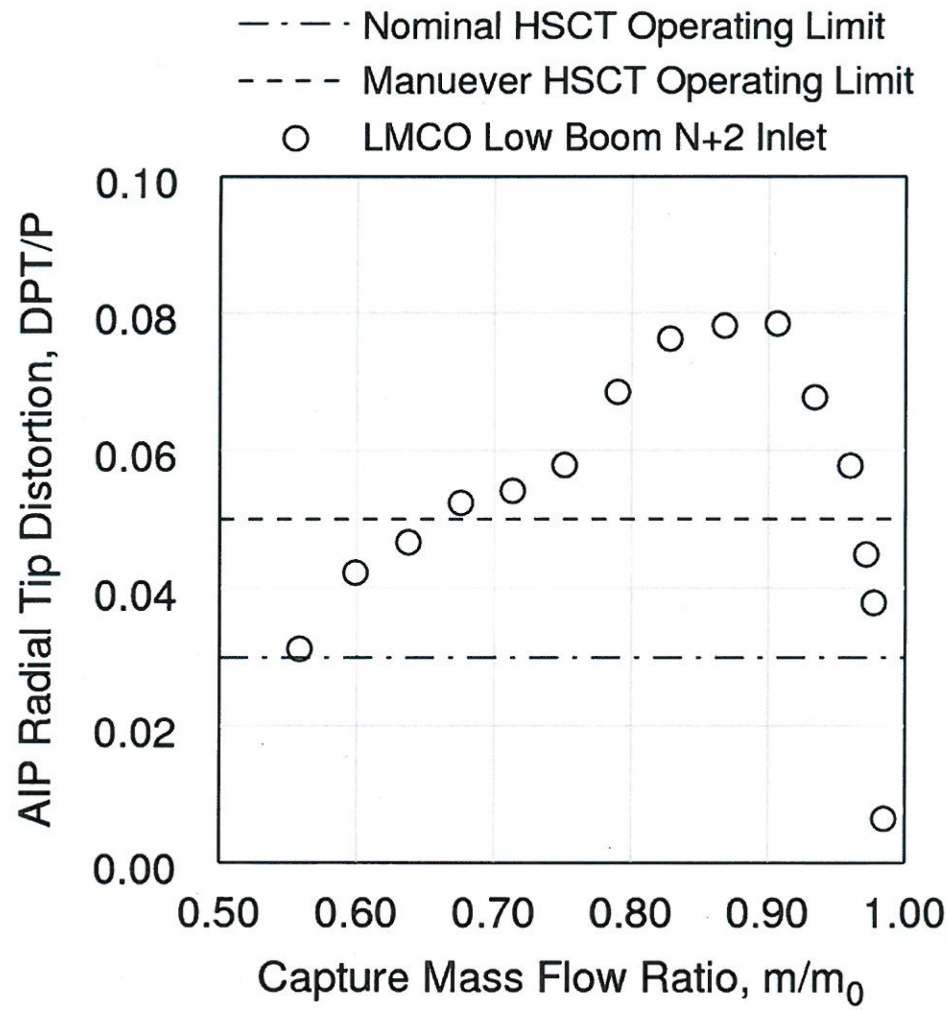


Circumferential Distortion, DPC/P

N+2 Low Boom Supersonic Inlet Design Study
AIP Distortion Characteristics

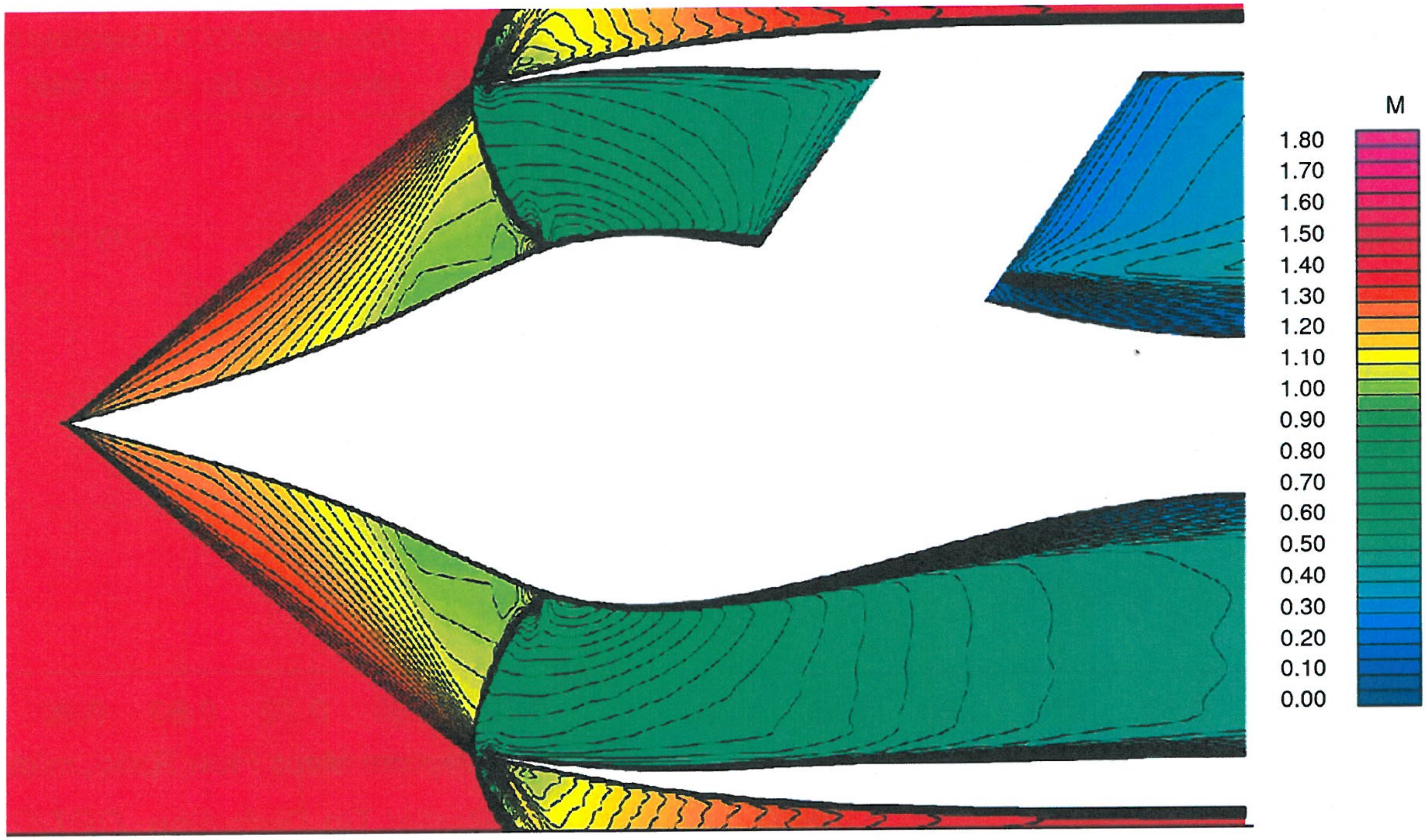


Radial Hub Distortion, DPH/P

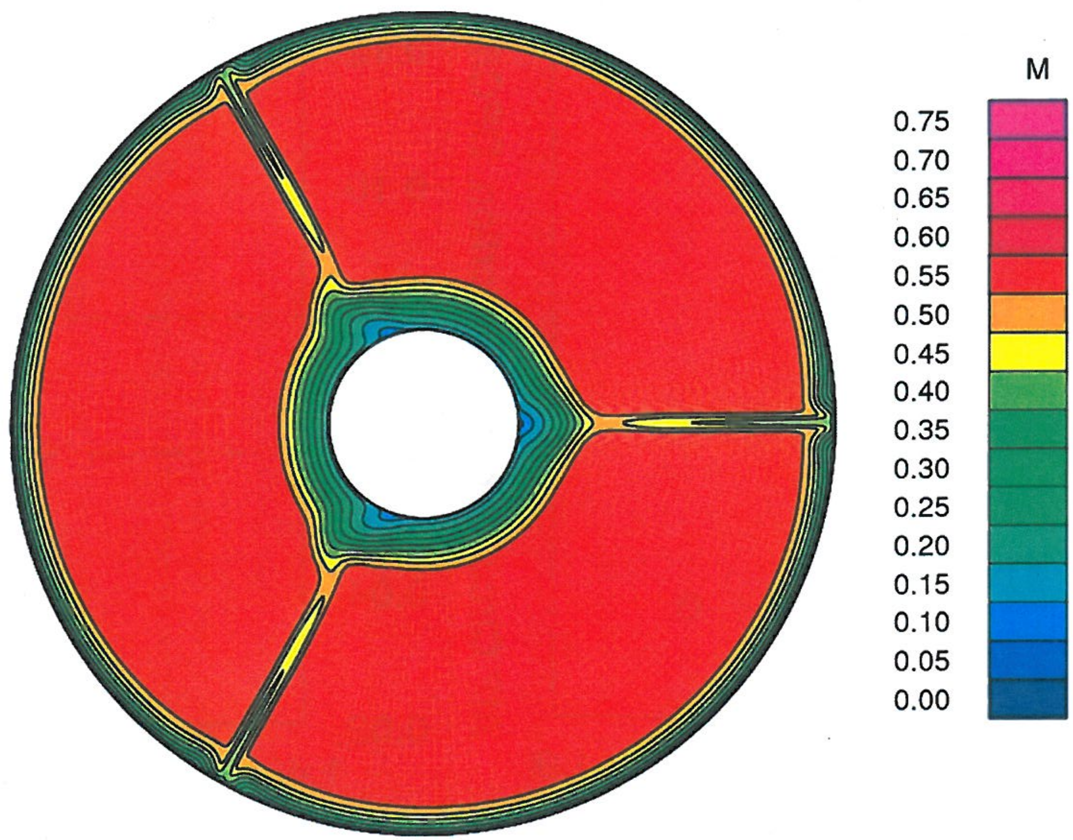


Radial Tip Distortion, DPT/P

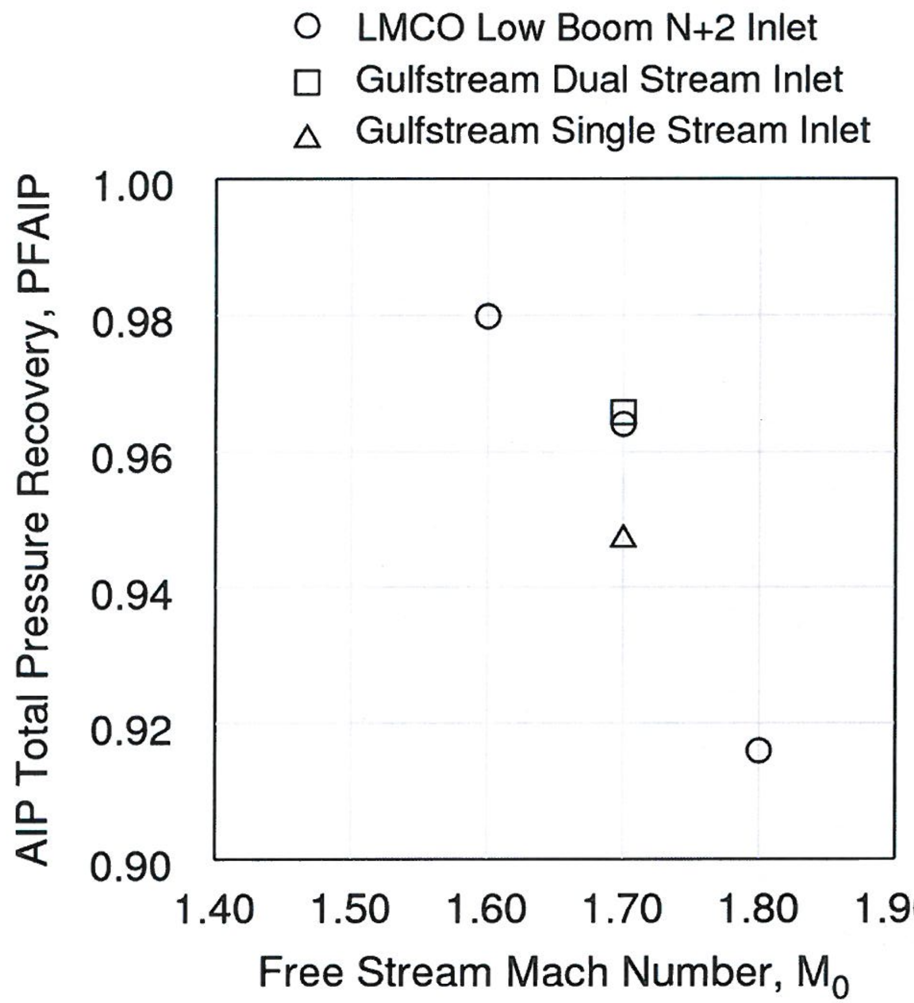
N+2 Low Boom Supersonic Inlet Design Study
Critical Inlet Operating Condition, $M_0 = 1.7$
Streamwise Mach Number Contours



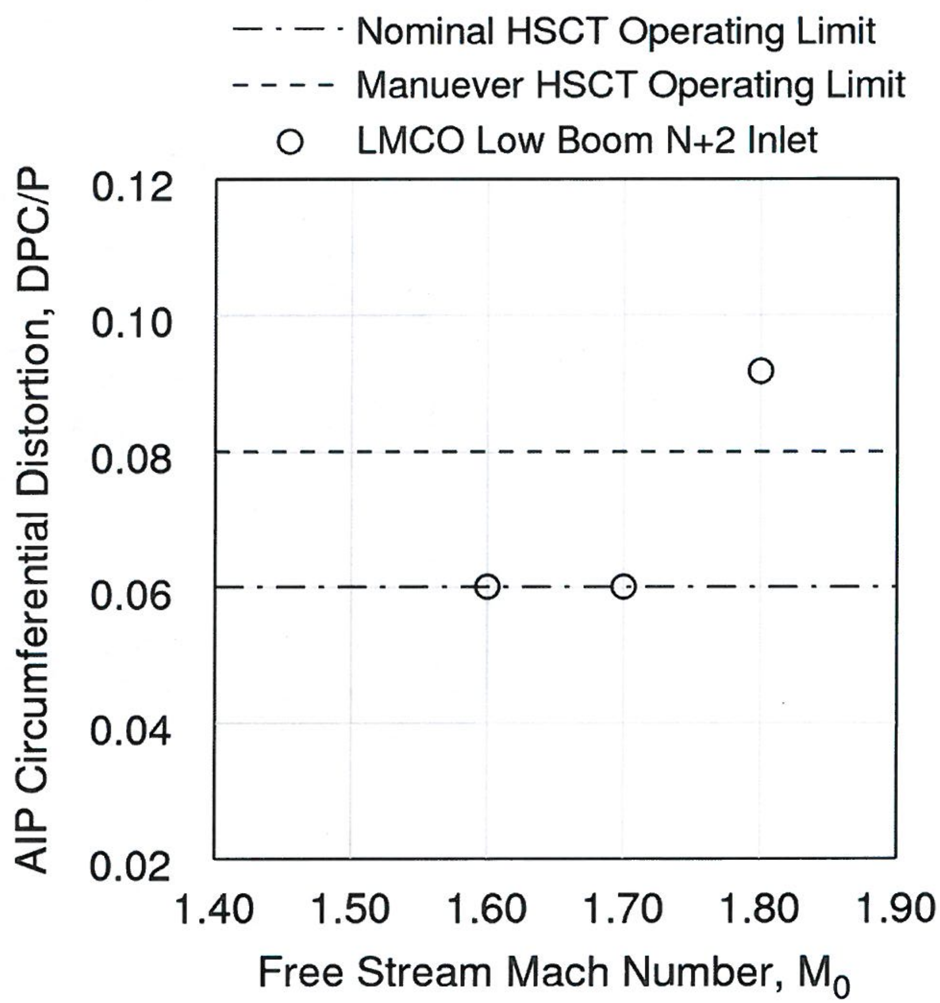
N+2 Low Boom Supersonic Inlet Design Study
Critical Inlet Operating Condition, $M_0 = 1.7$
AIP Station Mach Number Contours



N+2 Low Boom Supersonic Inlet Design Study
Impact of Free Stream Mach Number, M_0

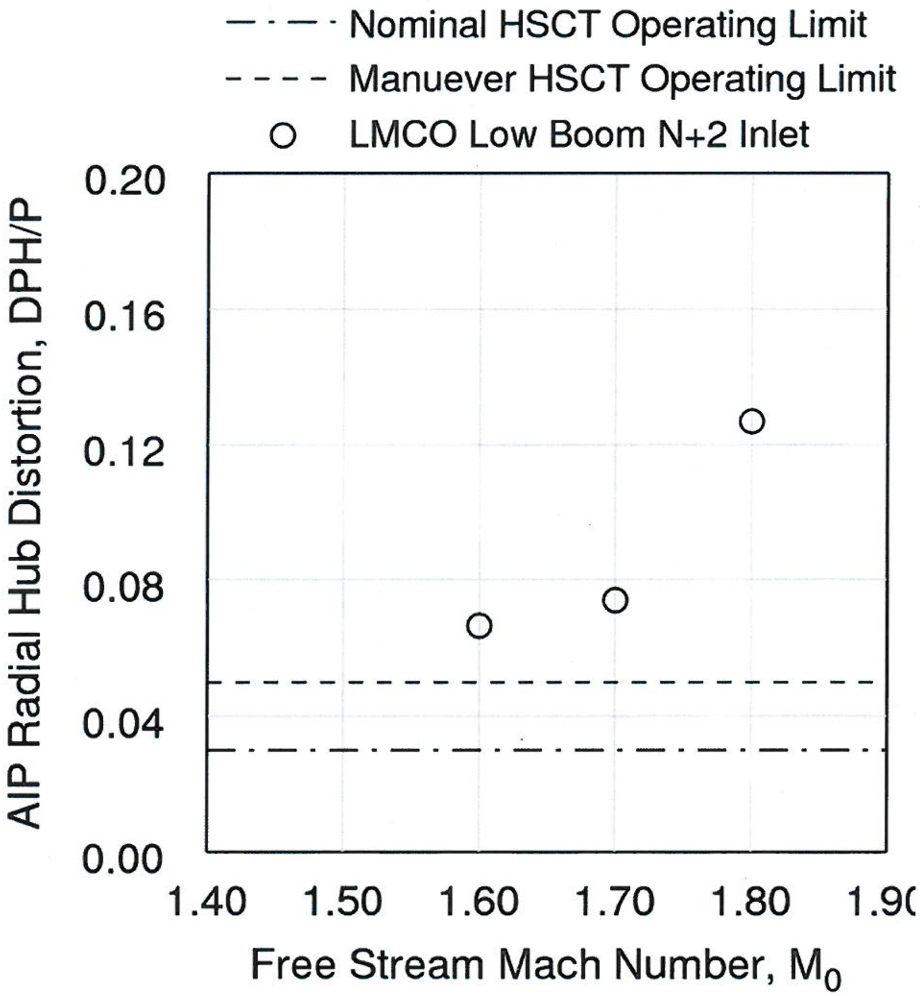


Total Pressure Recovery, PFAIP

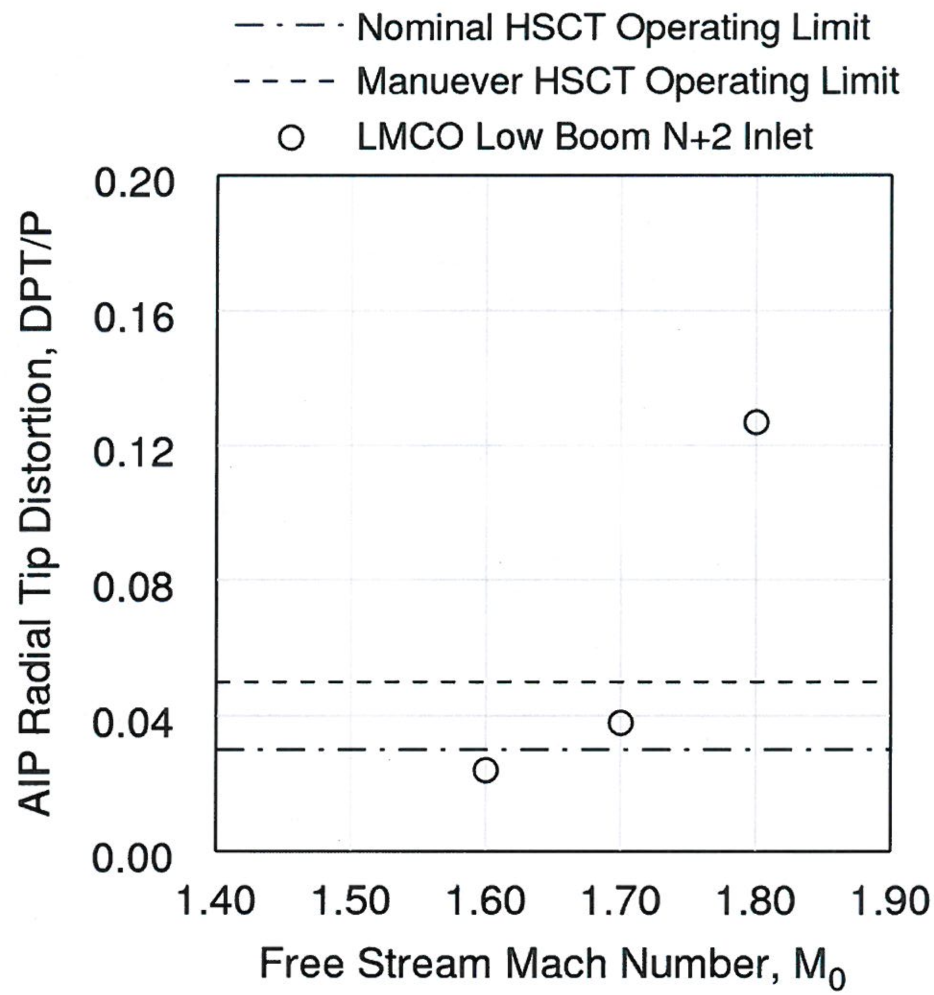


Circumferential Distortion, DPC/P

N+2 Low Boom Supersonic Inlet Design Study
Impact of Free Stream Mach Number, M_0

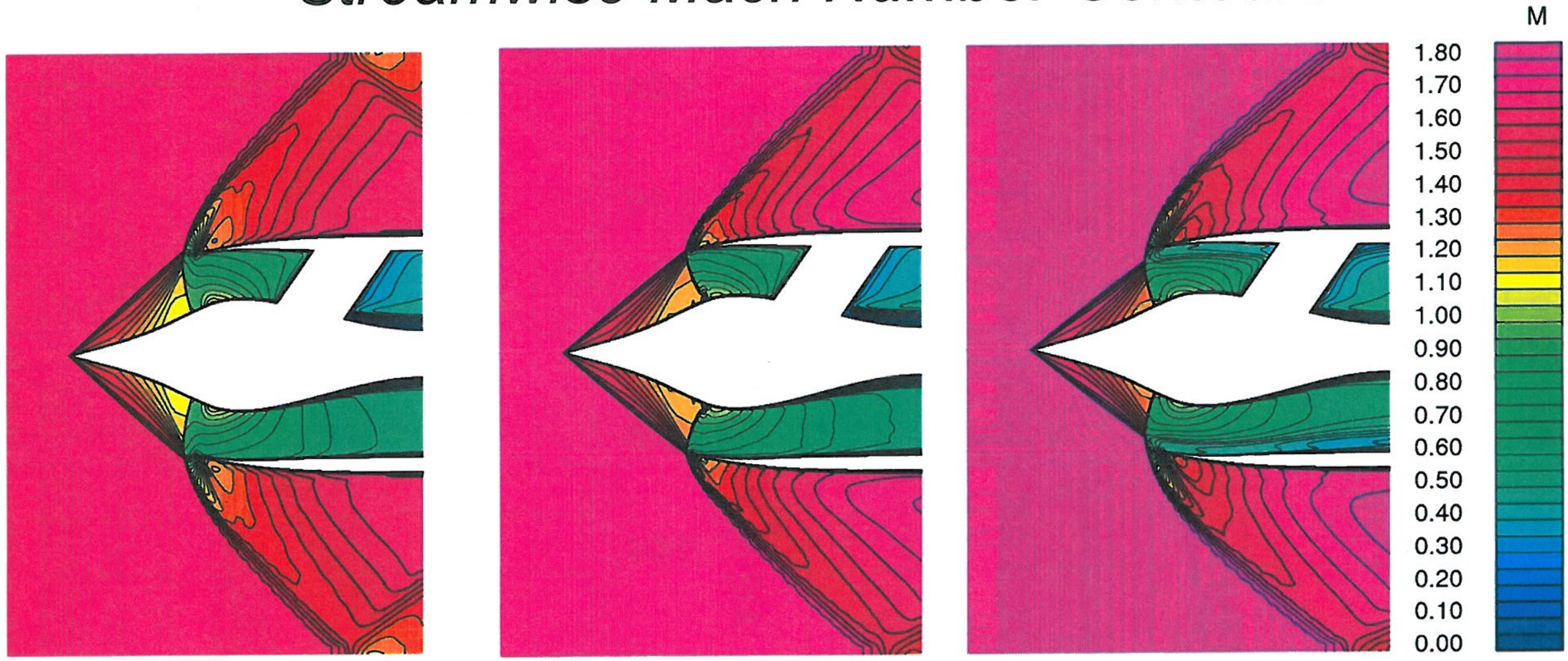


Radial Hub Distortion, DPH/P



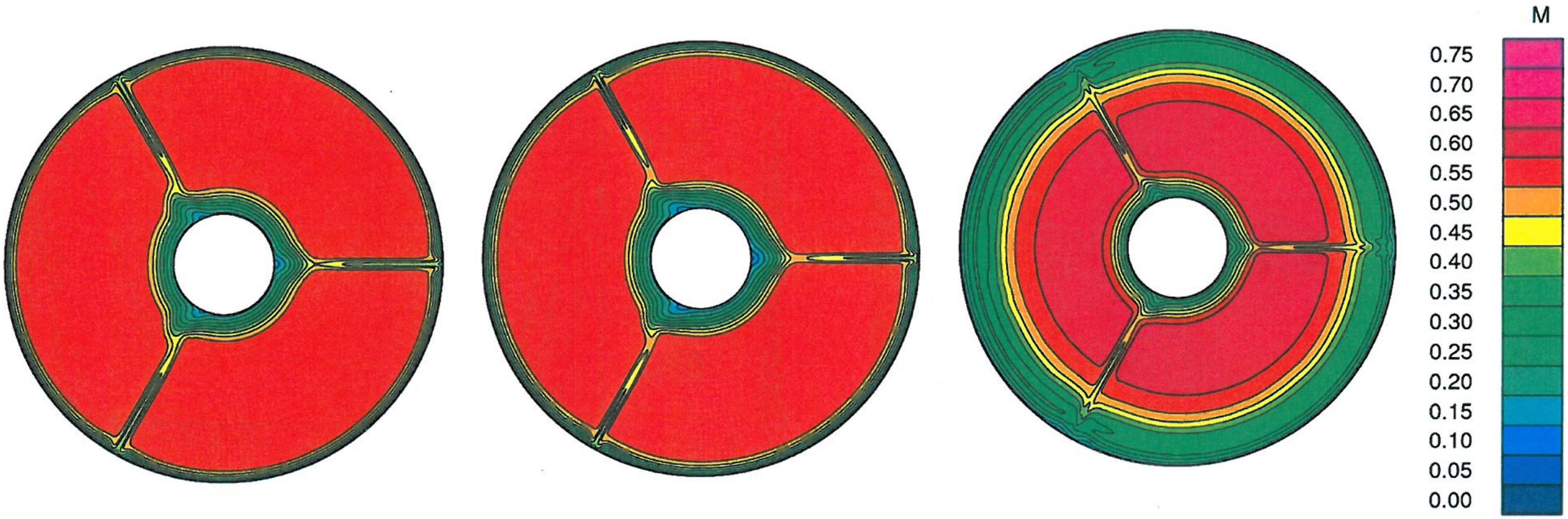
Radial Tip Distortion, DPT/P

N+2 Low Boom Supersonic Inlet Design Study
Impact of Free Stream Mach Number, M_0
Streamwise Mach Number Contours



$M_0 = 1.6$ $M_0 = 1.7$ $M_0 = 1.8$

N+2 Low Boom Supersonic Inlet Design Study
Impact of Free Stream Mach Number, M_0
AIP Station Mach Number Contours

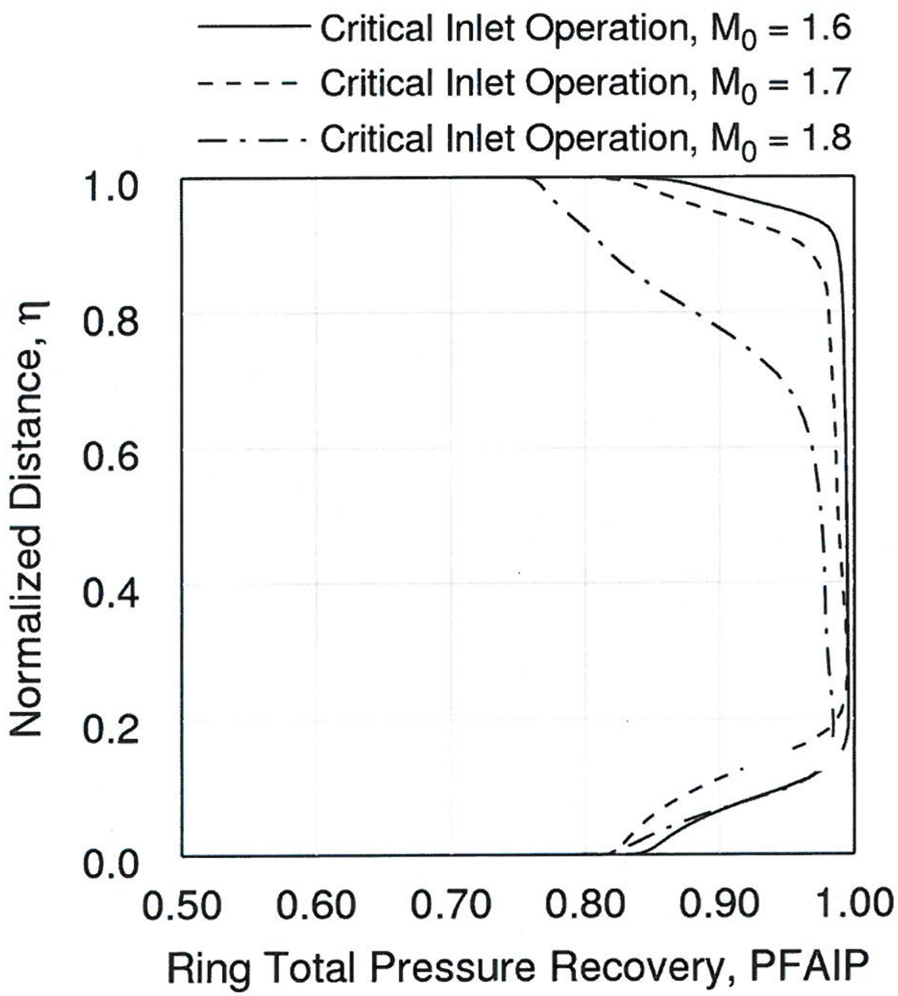


M_0= 1.6

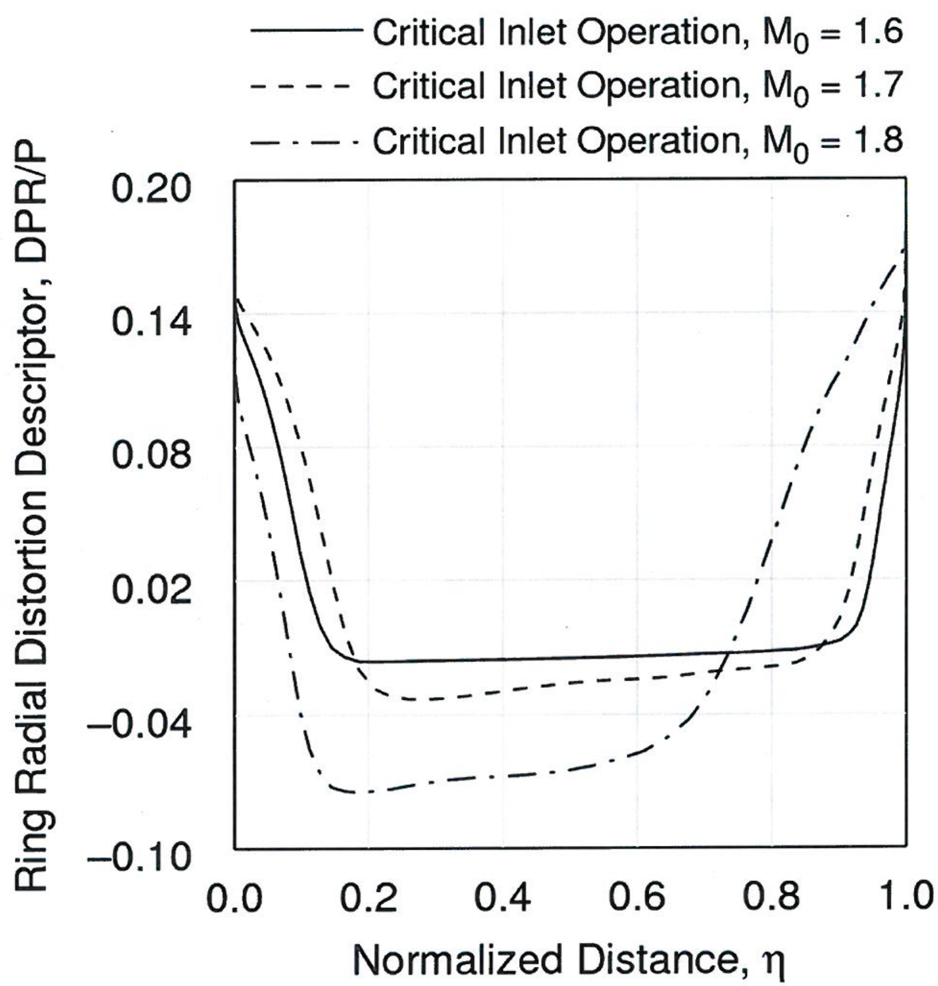
M_0= 1.7

M_0= 1.8

N+2 Low Boom Supersonic Inlet Design Study
Impact of Free Stream Mach Number, M_0

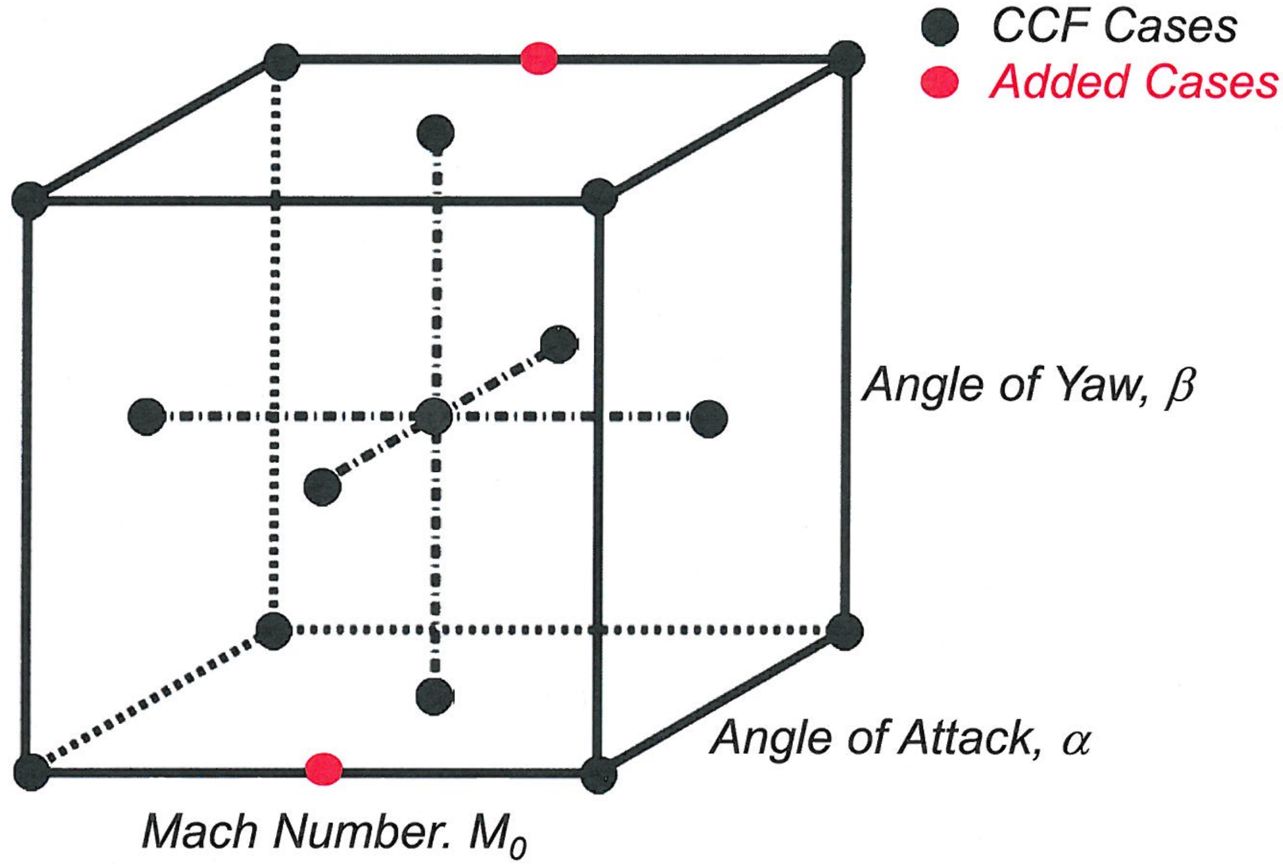


Ring Total Pressure Recovery, PFAIP



Ring Radial Distortion, DPR/P

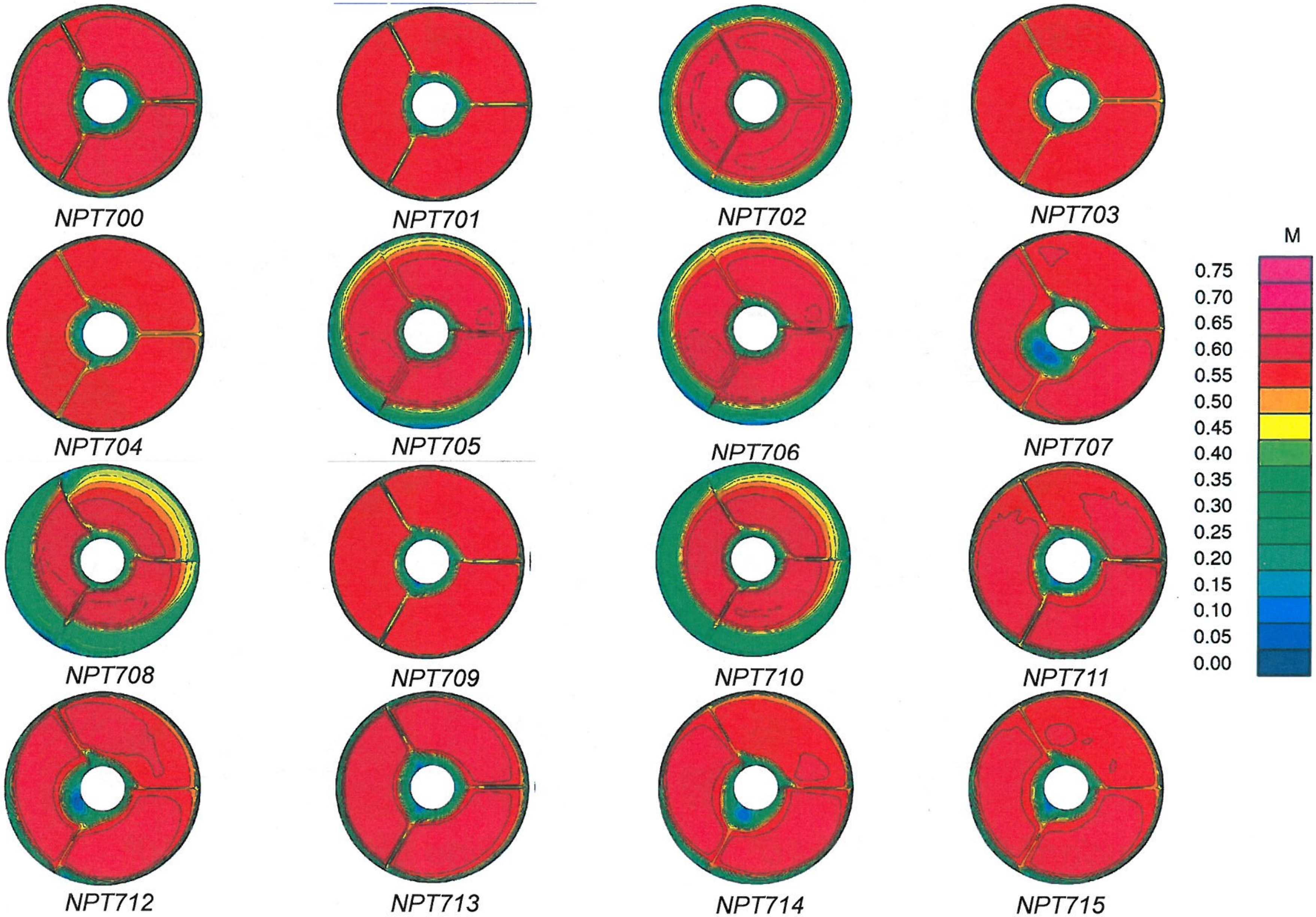
N+2 Low Boom Supersonic Inlet Design Study
Task (2): Central Composite DOE Operability Design



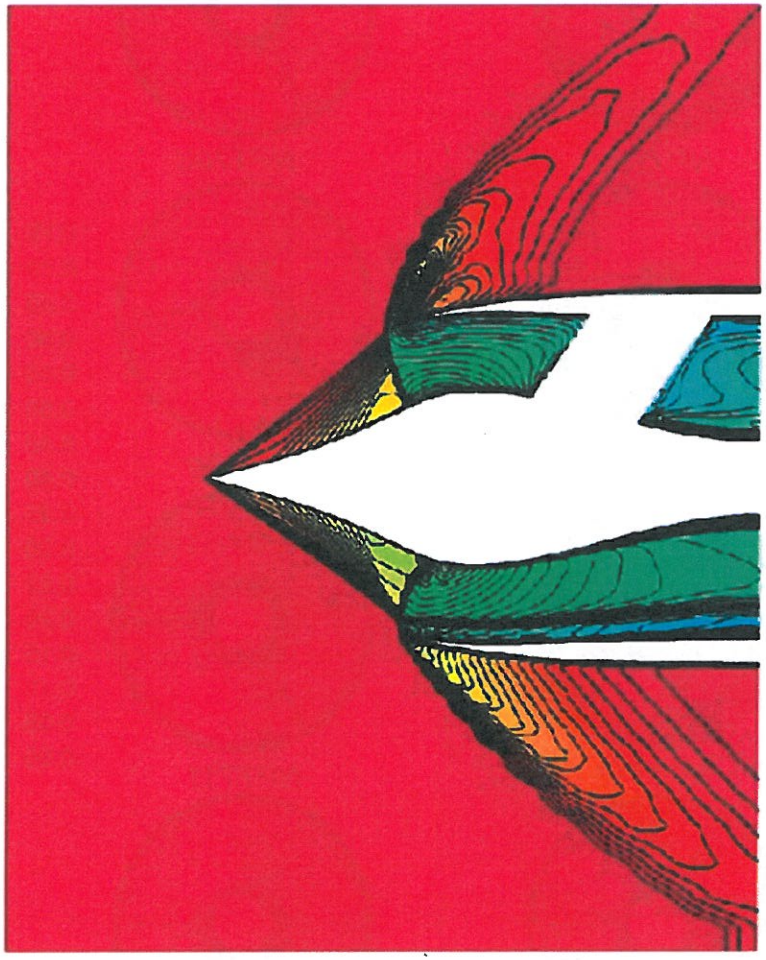
N+2 Low Boom Supersonic Inlet Design Study
Task (2): Central Composite DOE Operability Design
Fine Grid, 27.686×10^6

Case	M_0	α	β	PFAIP	DPH/P	DPT/P	DPC/P
NPT700	1.70	0.0	0.0	0.96288	0.07610	0.04434	0.07272
NPT701	1.60	0.0	0.0	0.97609	0.06595	0.02799	0.06797
NPT702	1.80	0.0	0.0	0.90164	0.03577	0.10430	0.07701
NPT703	1.60	4.0	0.0	0.97341	0.07370	0.02973	0.06547
NPT704	1.80	4.0	0.0	0.90980	0.04078	0.09930	0.07653
NPT705	1.60	0.0	4.0	0.97797	0.05362	0.02882	0.09782
NPT706	1.80	0.0	4.0	0.91375	0.04379	0.12796	0.13983
NPT707	1.60	4.0	4.0	0.96008	0.08271	0.02025	0.10564
NPT708	1.80	4.0	4.0	0.90000	0.03981	0.09546	0.11789
NPT709	1.60	2.0	2.0	0.97874	0.06115	0.02532	0.10561
NPT710	1.80	2.0	2.0	0.89908	0.04191	0.09743	0.11704
NPT711	1.70	0.0	2.0	0.96506	0.07334	0.04046	0.11830
NPT712	1.70	4.0	2.0	0.94790	0.07099	0.07283	0.11601
NPT713	1.70	2.0	0.0	0.96964	0.06640	0.05484	0.07605
NPT714	1.70	2.0	4.0	0.95447	0.06361	0.06343	0.13888
NPT715	1.70	2.0	2.0	0.95800	0.07494	0.05418	0.11878
NPT716	1.70	4.0	4.0	0.93967	0.07881	0.06168	0.12353

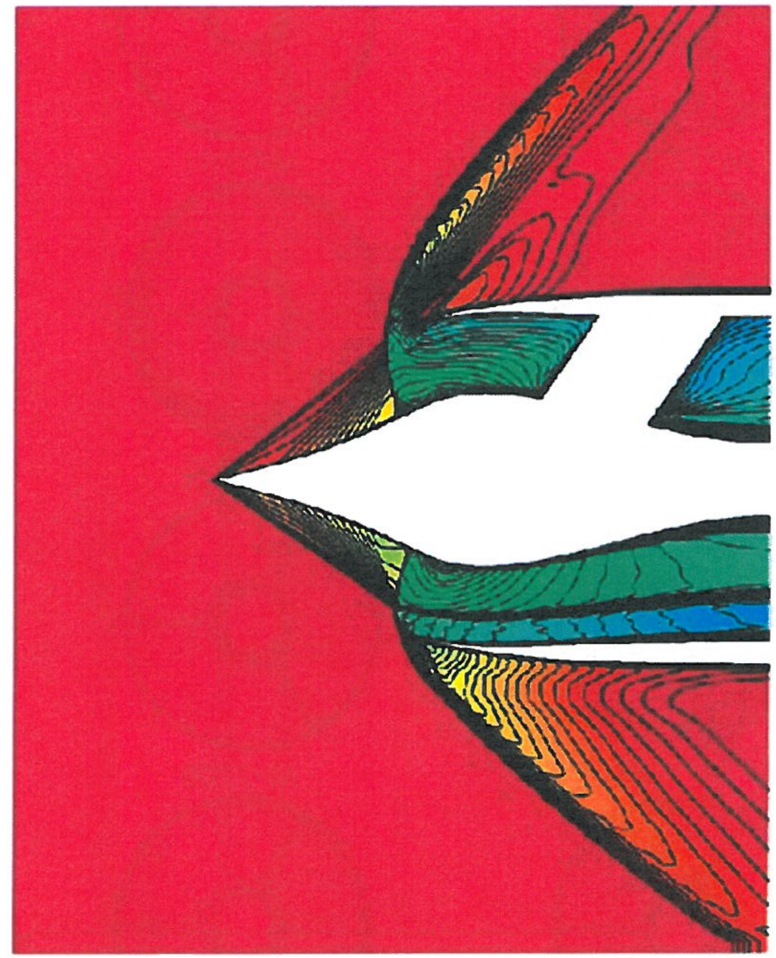
N+2 Low Boom Supersonic Inlet Design Study
Task (2): Central Composite DOE Operability Design
AIP Station Mach Number Contours



N+2 Low Boom Supersonic Inlet Design Study
Task (2): Grid Resolution Probability Bounds
Case NPT708, M_0=1.80, α=4.0°, β=4.0°

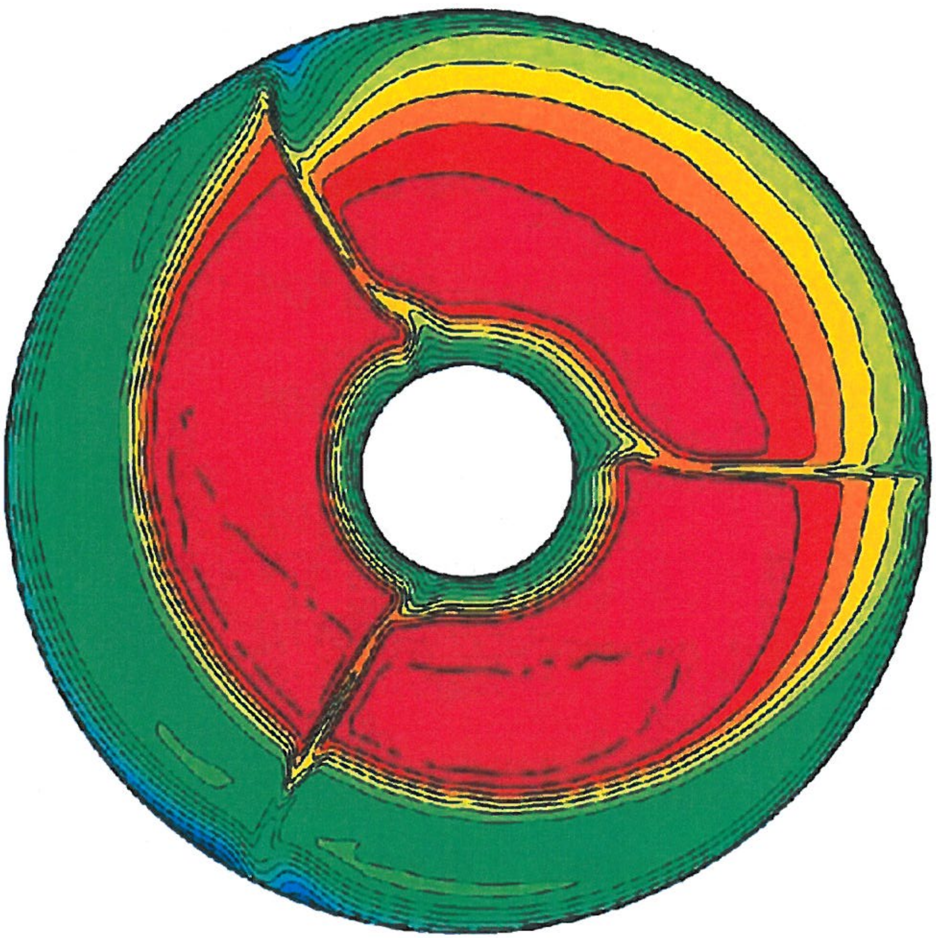


Standard Grid, 3.461×10^6

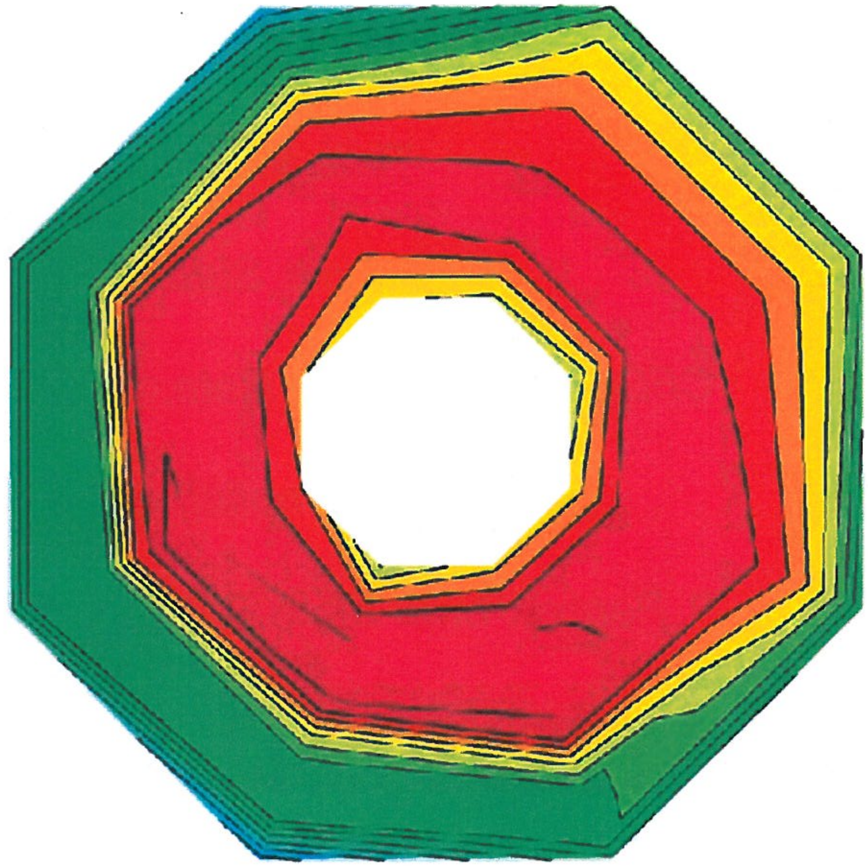


Fine Grid, 27.686×10^6

N+2 Low Boom Supersonic Inlet Design Study
Task (2): 80-Probe Rake Probability Bounds
Case NPT708, M_0=1.80, α=4.0°, β=4.0°



Computation Grid, 3.461×10^6



80-Probe AIP Rake

N+2 Low Boom Supersonic Inlet Design Study
Task (3) Unsteady Flow and Stochastic Models
Unsteady DES Factor Information

Time Variable	Value
CFD Time Step, Sec.	1.0×10^{-6}
CFD Data Sampling Rate, Samples/Sec(1)	1.0×10^{4}
CFD Data Sampling Span, Sec	1.5×10^{-2}
Per/rev Time Span (4300 RPM), Sec.	1.395×10^{-2}
Total Number of Data Samples	151

(1) Equivalent to experimental sampling rate, 1.0×10^{4} samples/sec

N+2 Low Boom Supersonic Inlet Design Study Task (3) Unsteady Flow and Stochastic Models Unsteady Time Series Methodology

- At each sampling site, i.e. every 1/10,000 of a second, the DES solution is spawned and the area average AIP total pressure recovery, DPH/P, DPT/P and DPC/P distortions are calculate and recorded

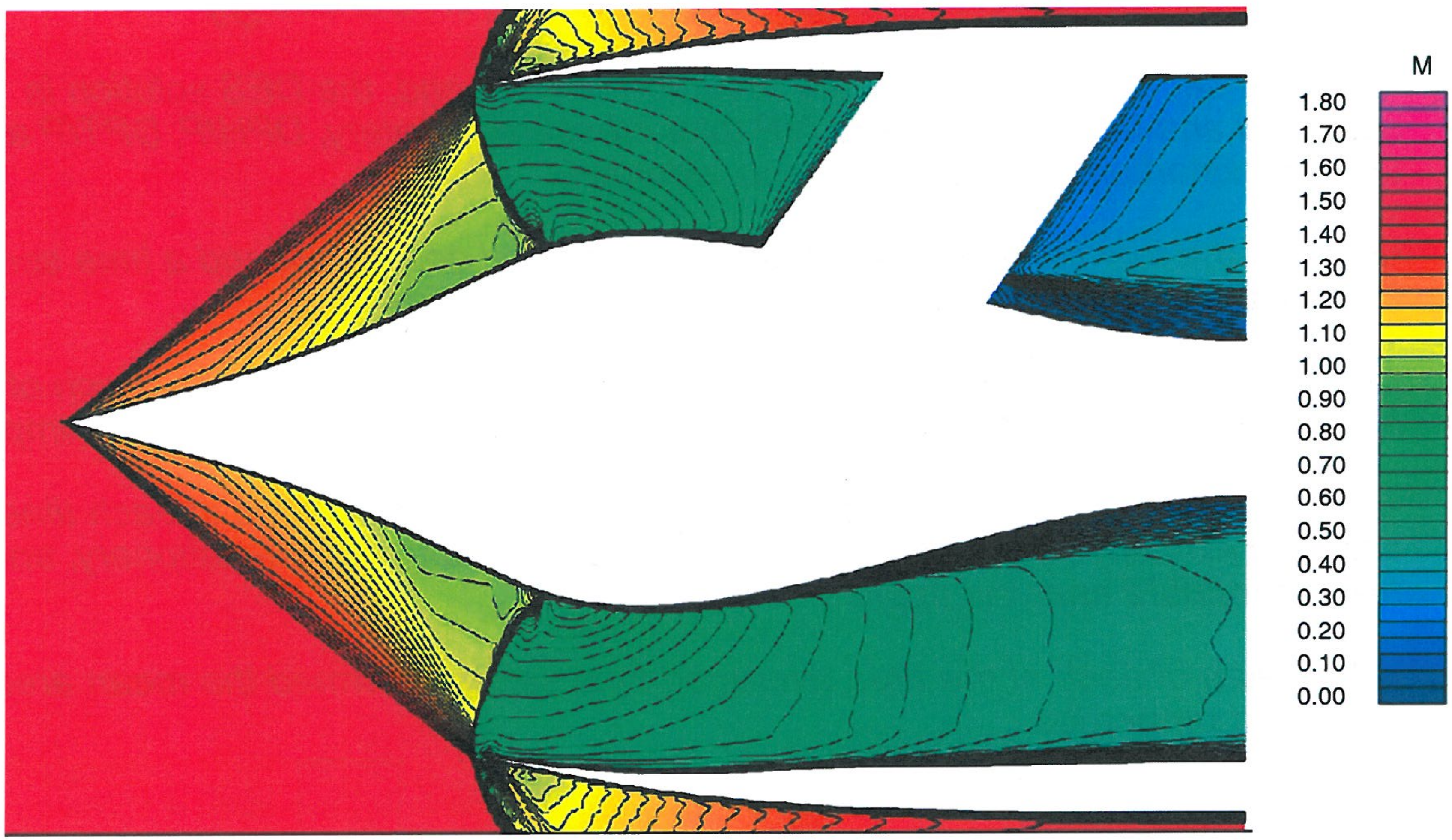
- Each of the four individual parameters are treated separately and a time series time history developed for the area averaged properties.

- Assuming a fan speed of 4,300 RPM, a time series is developed for each of the four parameters which covers one revolution of the fan blades, i.e. 151 samples.

- For each of the individual parameters, the stochastic properties of each time series is examined to determine whether it is stationary or non-stationary, and the appropriate analysis applied.

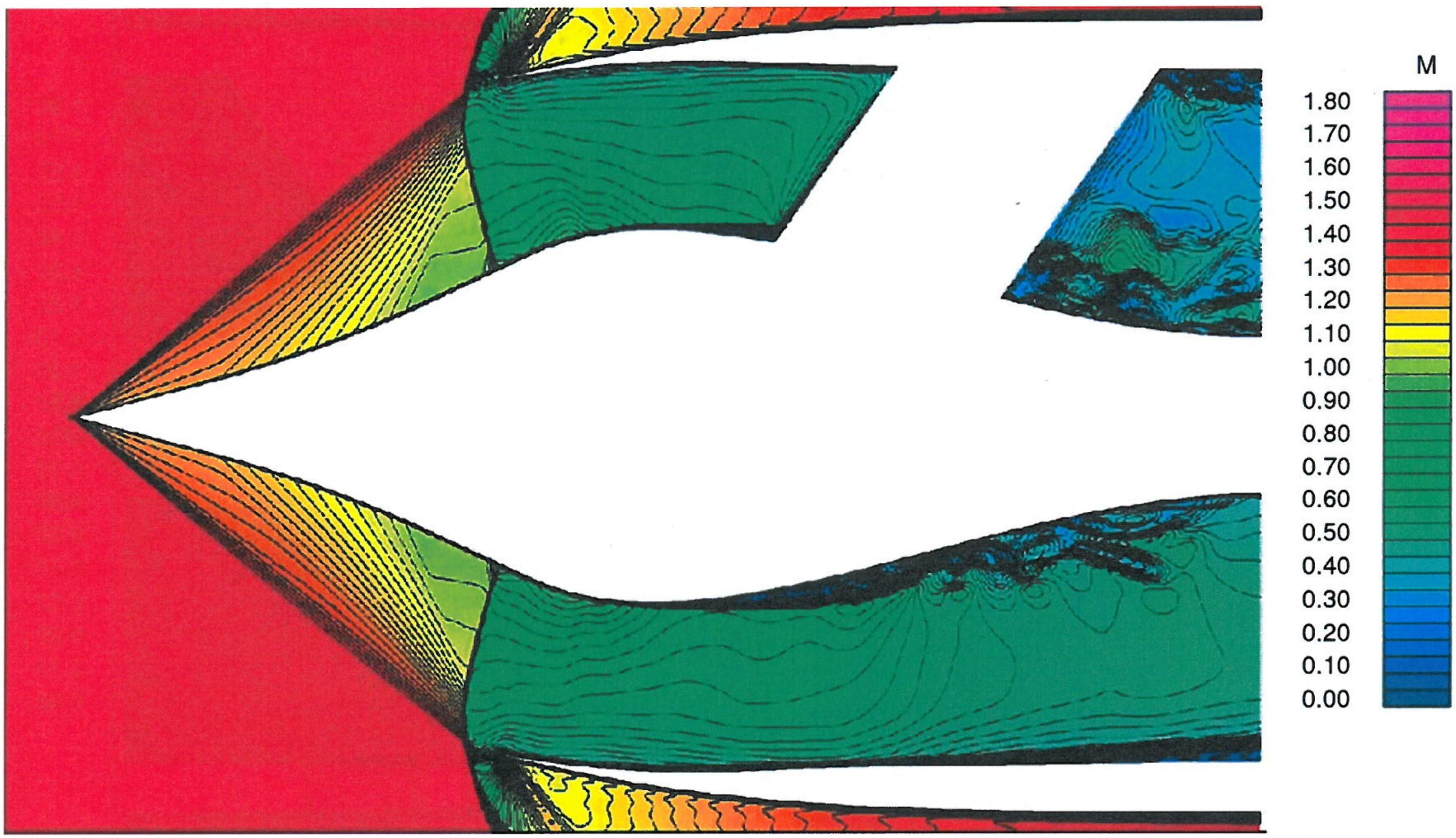
- The mean of each of the area averaged time series is termed the mean area averaged properties.

Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Critical Operating Point, M_0 =1.7



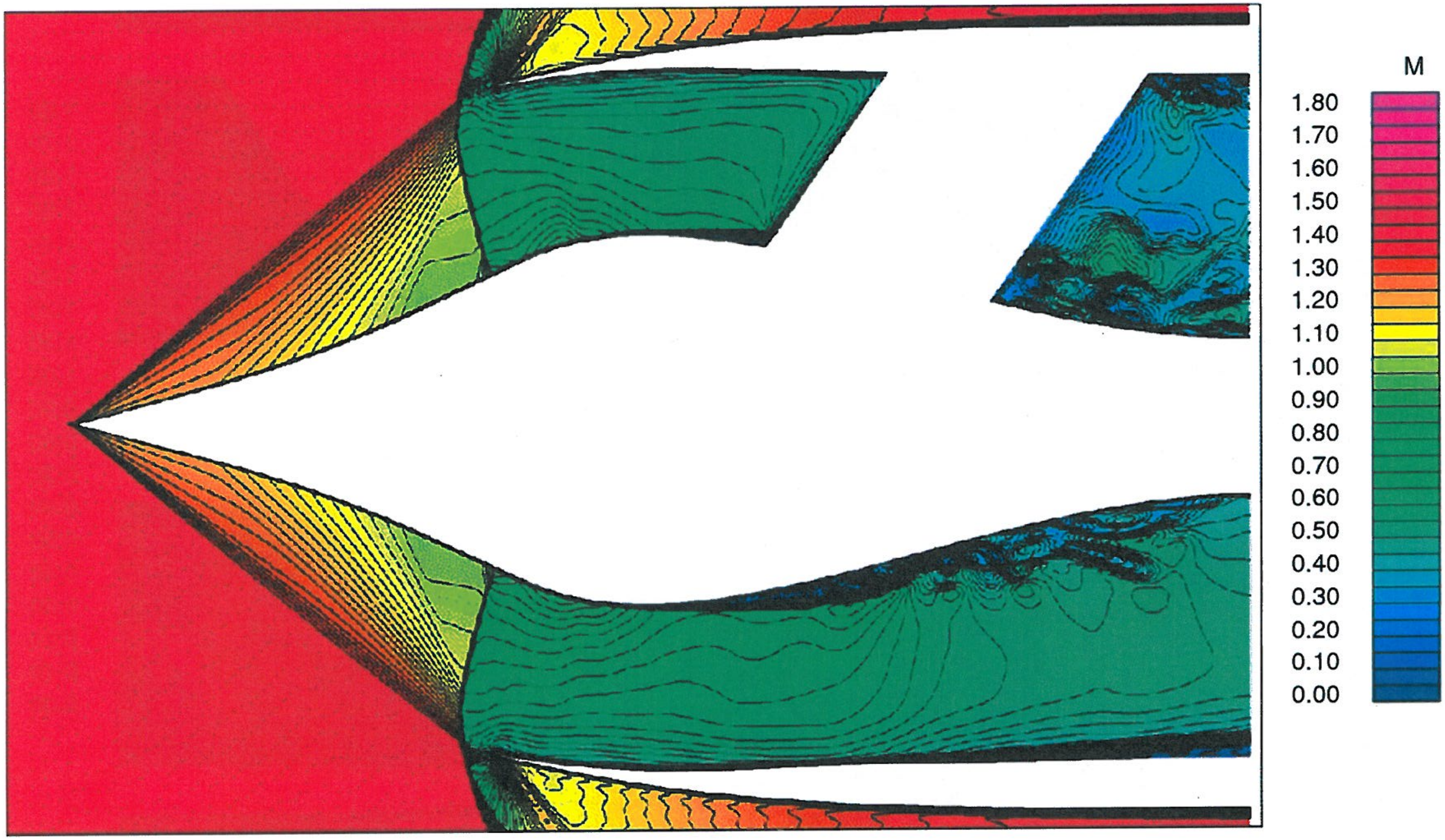
Steady 3D RANS Analysis

Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Critical Operating Point, M_0 =1.7



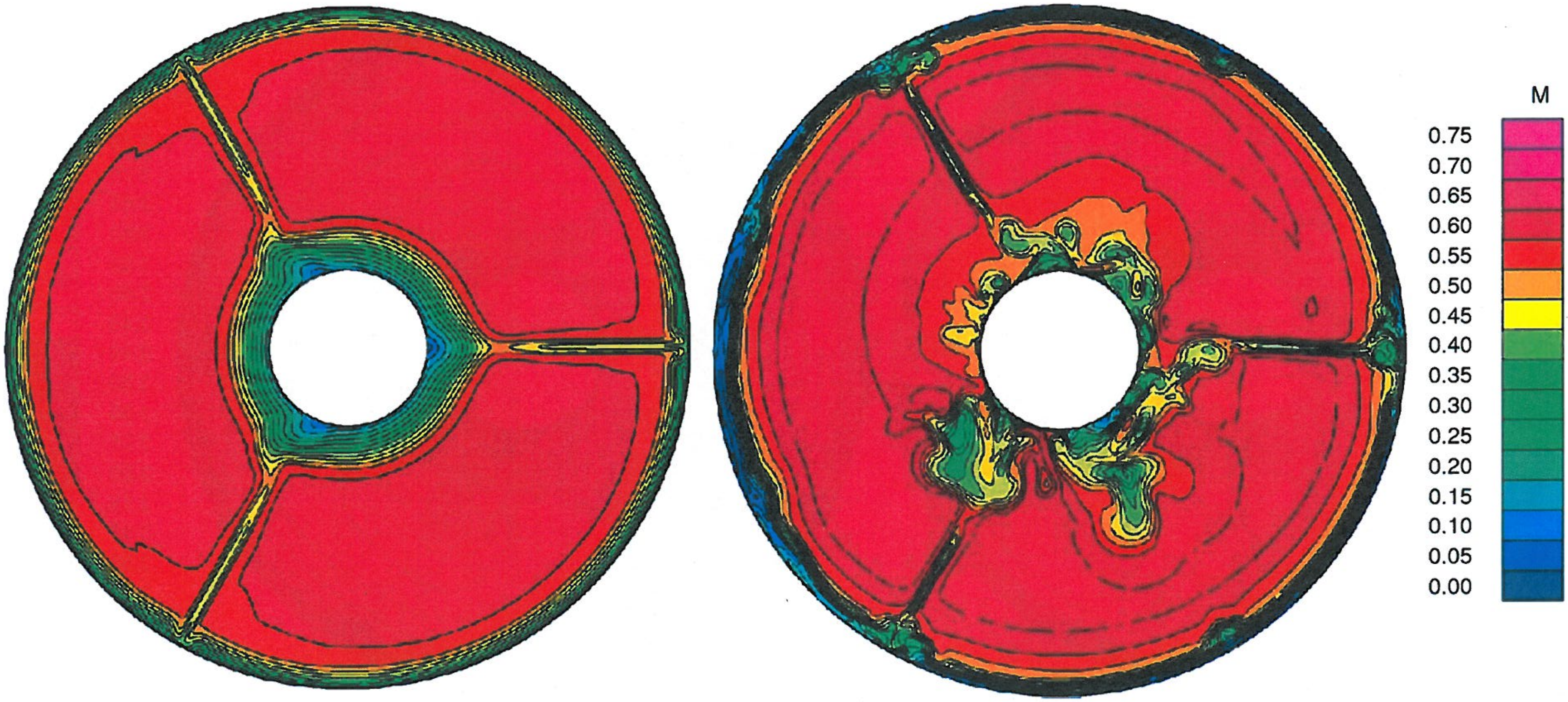
Unsteady 3D DES Analysis

Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Critical Operating Point, $M_0 = 1.7$



Unsteady 3D DES Analysis

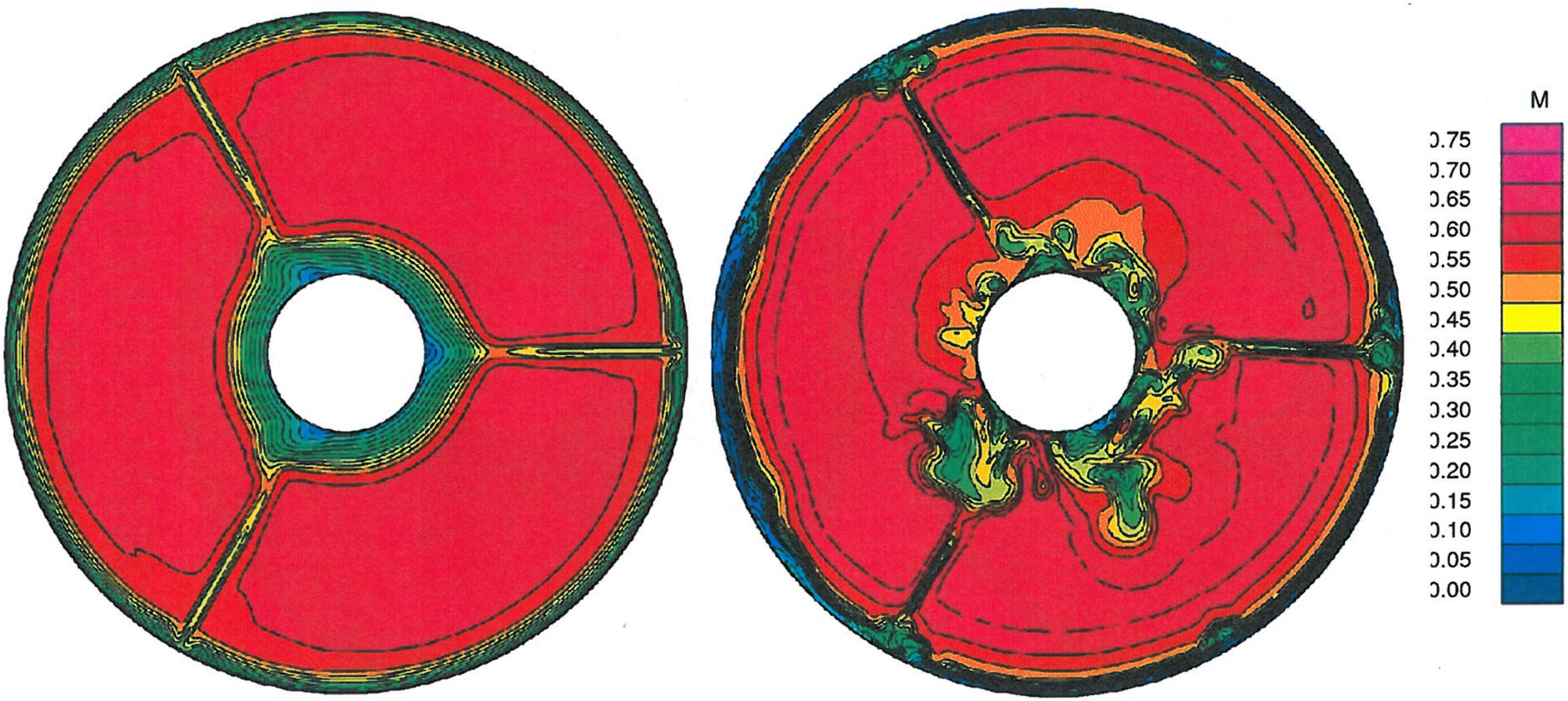
Task (3) Unsteady Flow and Stochastic Models
AIP Station Mach Number Contours
Critical Operating Point, M_0 =1.7



Steady 3D RANS Analysis

Unsteady 3D DES Analysis

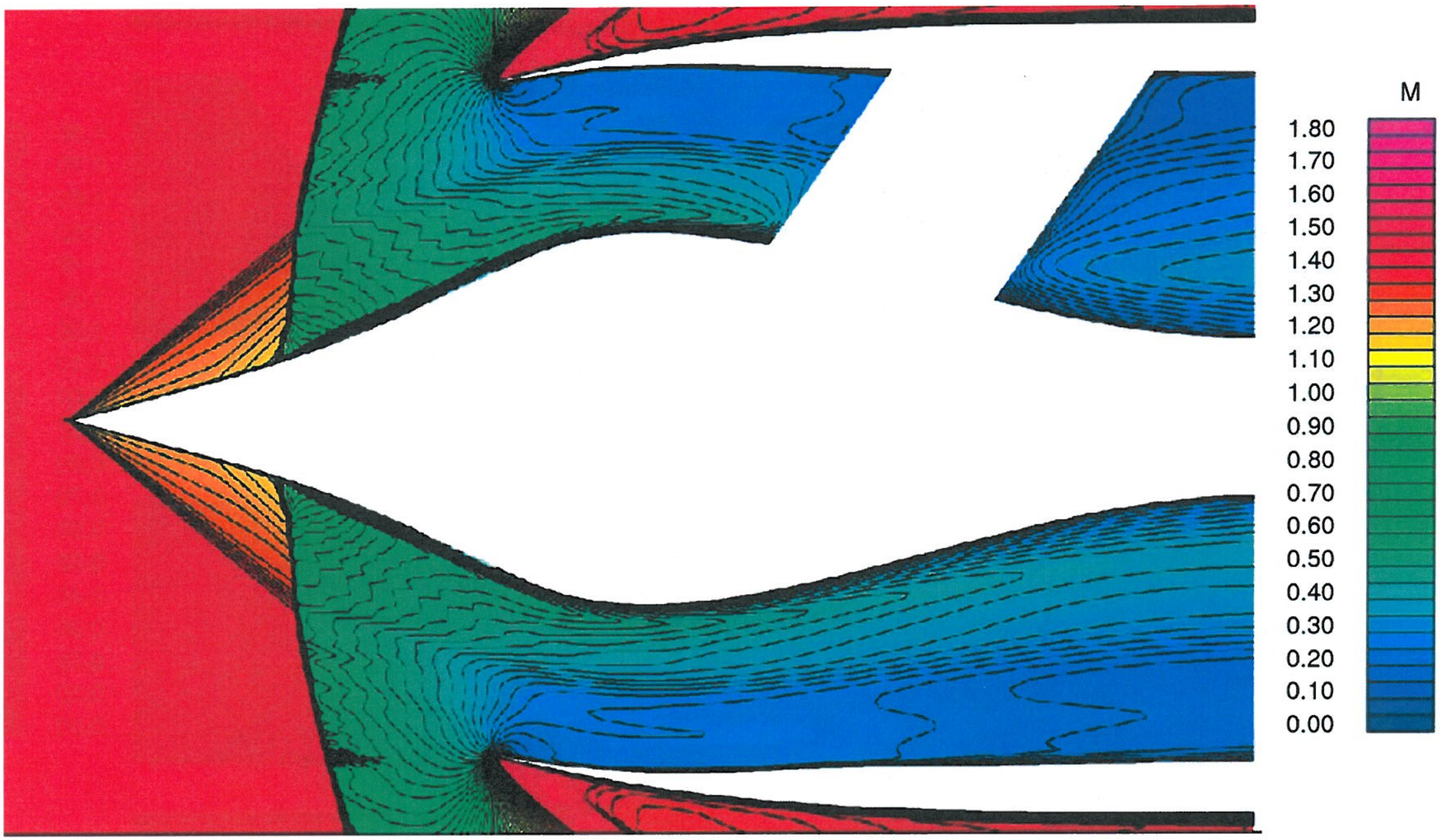
Task (3) Unsteady Flow and Stochastic Models
AIP Station Mach Number Contours
Critical Operating Point, M_0 =1.7



Steady 3D RANS Analysis

Unsteady 3D DES Analysis

Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Last Stable Operating Point, M_0 =1.7



Steady 3D RANS Analysis

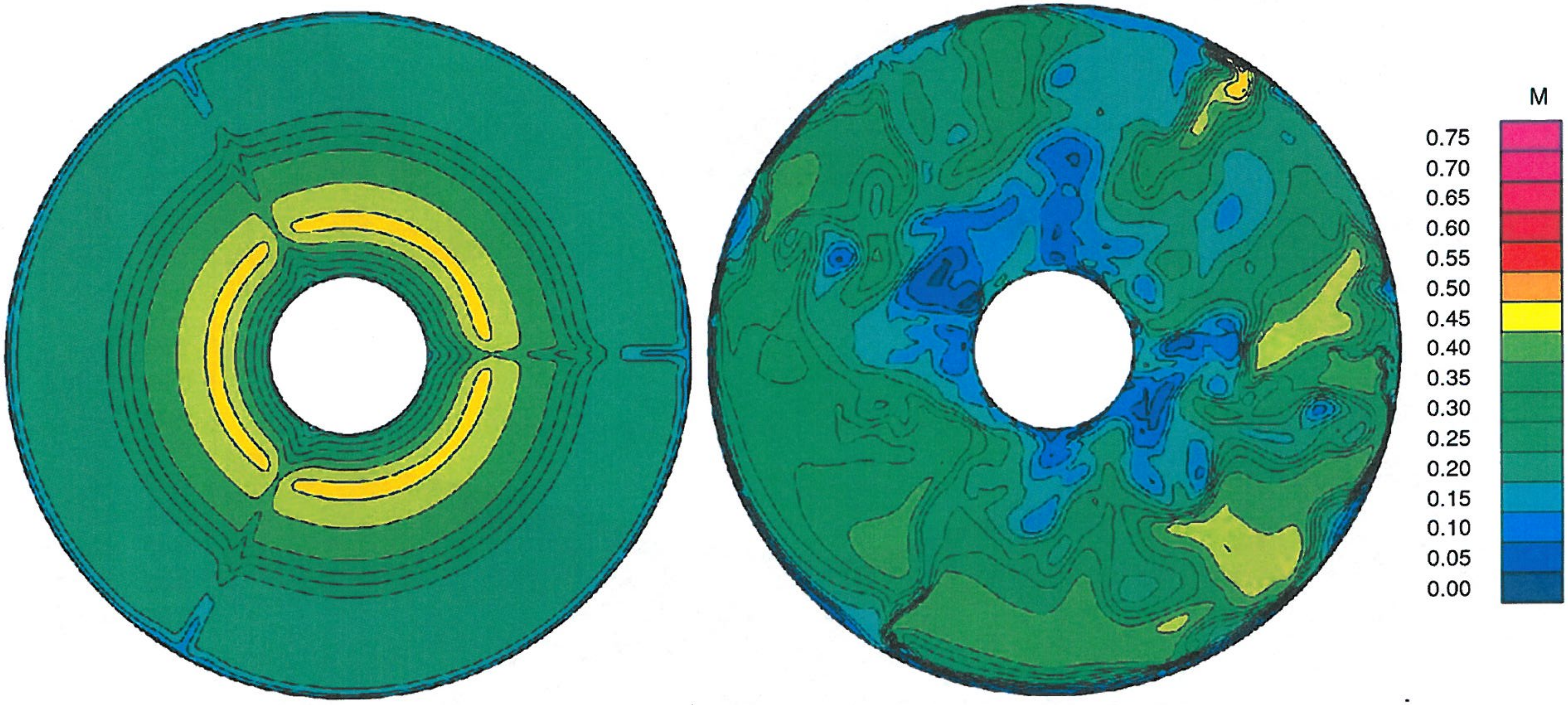
Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Last Stable Operating Point, $M_0 = 1.7$

Unsteady 3D DES Analysis

Task (3) Unsteady Flow and Stochastic Models
Streamwise Mach Number Contours
Last Stable Operating Point, M_0 =1.7

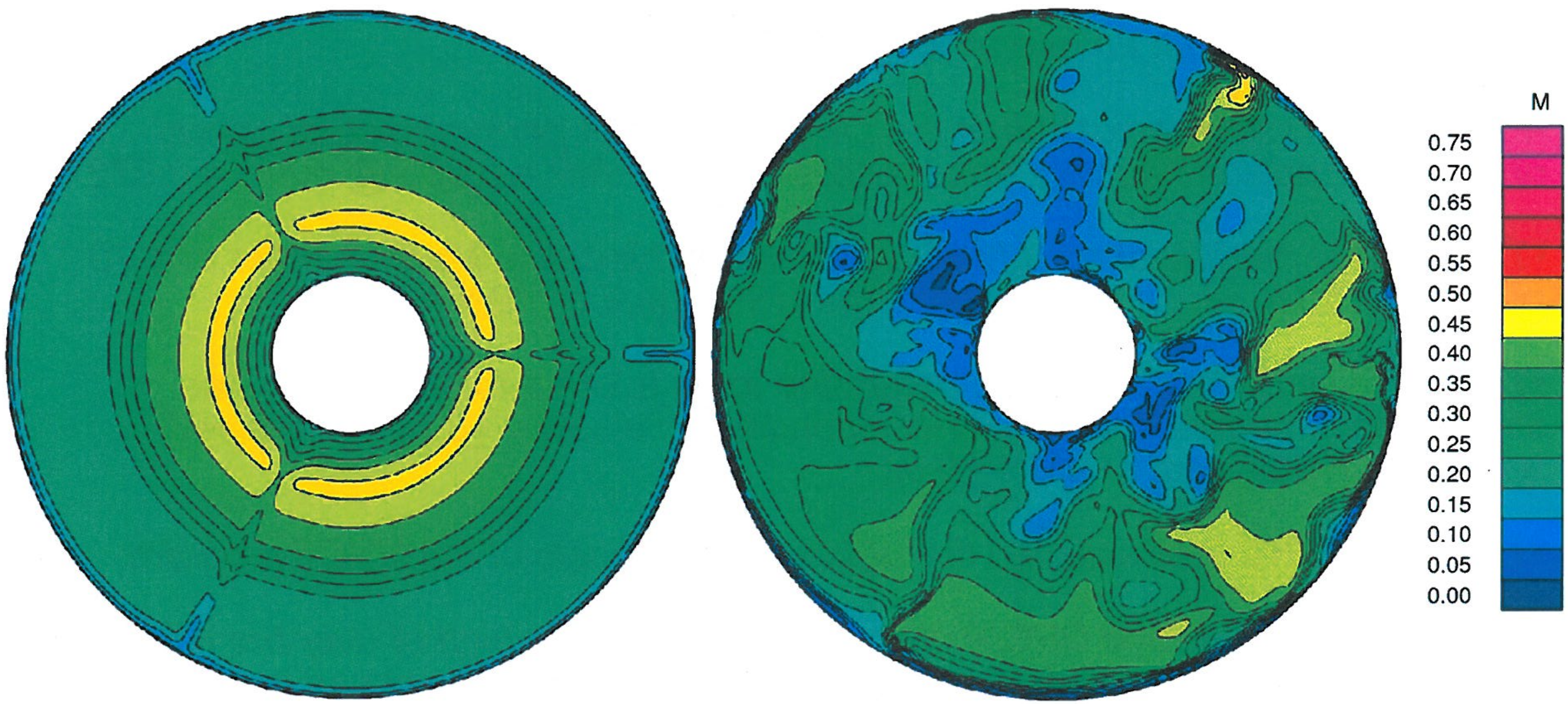
Unsteady 3D DES Analysis

Task (3) Unsteady Flow and Stochastic Models
AIP Station Mach Number Contours
Last Stable Operating Point, M_0 =1.7



Steady 3D RANS Analysis *Unsteady 3D DES Analysis*

Task (3) Unsteady Flow and Stochastic Models
AIP Station Mach Number Contours
Last Stable Operating Point, M_0 =1.7



Steady 3D RANS Analysis

Unsteady 3D DES Analysis

N+2 Low Boom Supersonic Inlet Design Study
General Observations

- *The most striking feature of the LMCO N+2 inlet design is the very short subsonic diffuser with an overall length ratio L/D = 1.116.*

- *Preliminary results indicate that the LMCO N+2 inlet performance at critical operating condition has very good recovery, i.e. PFAIP = 0.965 @ m/m_0 = 0.972.*

- *The stability margin for the LMCO N+2 Inlet at the cruise Mach number of 1.70 is $\Delta SM \geq 45.1\%$ which is well above the HSCT goal of $\Delta SM = 10.0\%$.*

- *The LMCO inlet has also been determine to be tolerant to changes in free stream Mach number from the cruise condition, i.e. $\Delta M = \pm 0.10$. This is well above the HSCT goal of $\Delta M = \pm 0.05$*

- *The LMCO N+2 inlet satisfied the α/β operability goals of the HSCT program.*

- *The DPH/P, DPT/P and DPC/P distortion is moderately high of over the HSCT operability range, but could easily be managed with a well designed non-bleed flow control system.*

N+2 Low Boom Supersonic Inlet Design Study Recommendations

It is recommended the NASA should continue to develop the LMCO N+2 Low Boom supersonic inlet design to cover:

- *A comprehensive non-bleed flow control system to manage distortion over the complete operability range*

- *A methodology to achieve simple, elegant and good take-off performance, which should involve investigating "virtual lip shaping" methods to prevent lip flow separation on take-off.*

- *A modest and well-designed wind tunnel test is recommended, where the test goals could be accomplished in conjunction with modest SBIR effort.*